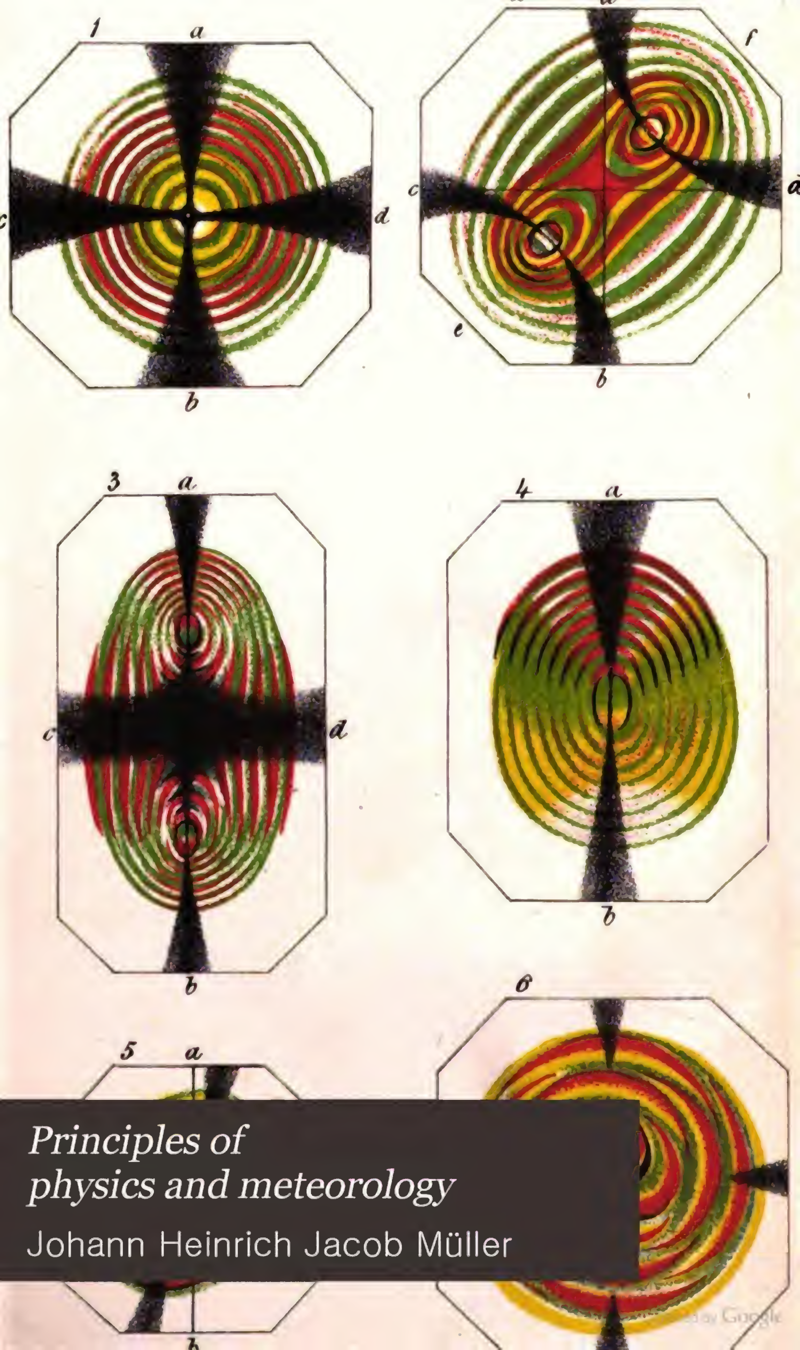
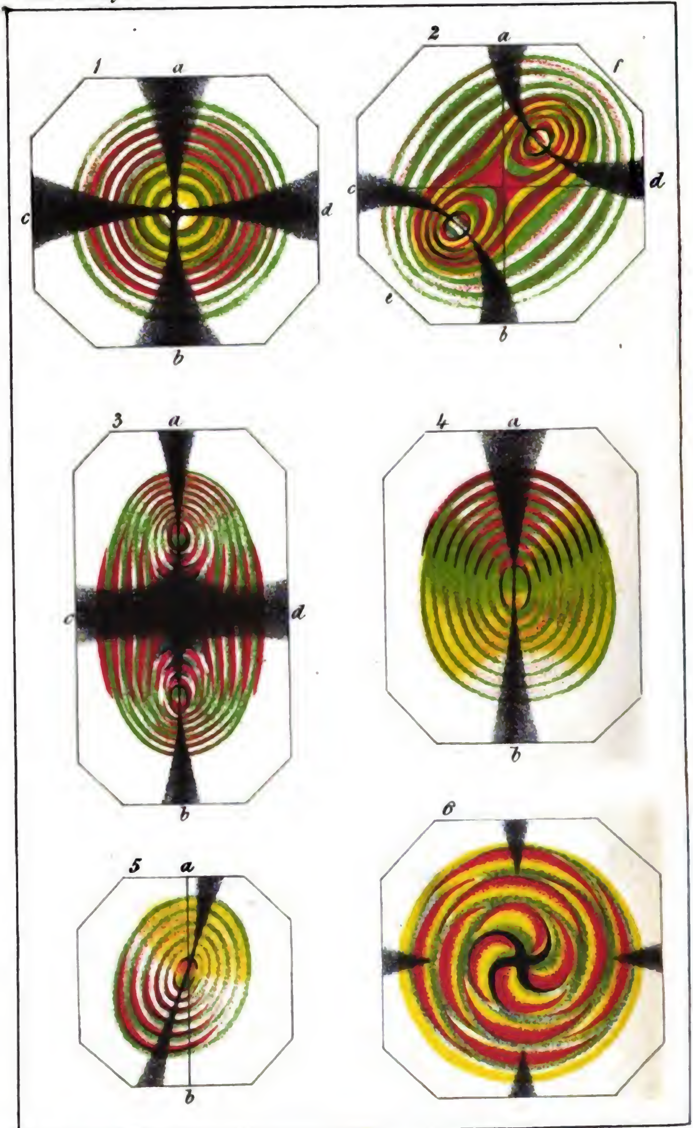


Principles of physics and meteorology

Johann Heinrich Jacob Müller

Muller



Madeley Lithog. 3 Wellington St. Strand

See Page 297.

PRINCIPLES

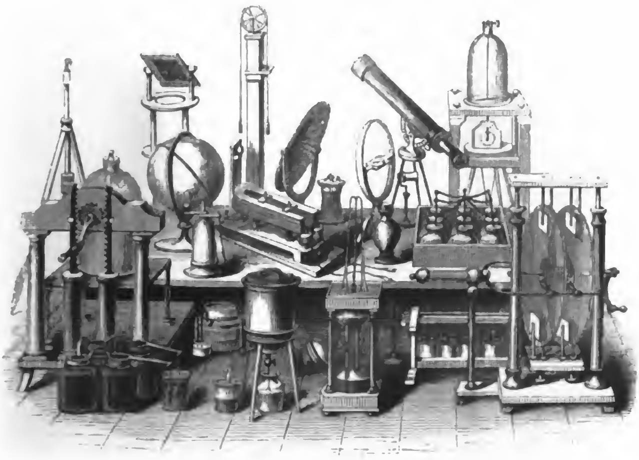
OF

PHYSICS AND METEOROLOGY.

Library of illustrated standard scientific works, no. 1

BY J. MULLER,

PROFESSOR OF PHYSICS AT THE UNIVERSITY OF FREIBURG.



ILLUSTRATED WITH 530 ENGRAVINGS ON WOOD, AND TWO COLOURED PLATES.

LONDON:

HIPPOLYTE BAILLIERE, PUBLISHER,

219, *REGENT STREET.*

PARIS: J. B. BAILLIERE, 13, RUE DE L'ECOLE DE MEDECINE.

1847.

PREFACE.

In laying the following pages before the Public, it seems necessary to state that the design of them is to render more easily accessible a greater degree of knowledge of the general principles of Physics and Meteorology than is usually to be obtained, without the sacrifice of a greater amount of time and labour than most persons can afford or are willing to make. The subjects of which this volume treats are very numerous—more numerous, in fact, than at first sight it would seem possible to embrace in so small a compass. The Author has, however, by a system of most judicious selection and condensation, been enabled to introduce all the most important facts and theories relating to Statics, Hydrostatics, Dynamics, Hydrodynamics, Pneumatics, the Laws of the Motions of Waves in general, Sound, the Theory of Musical Notes, the Voice and Hearing, Geometrical and Physical Optics, Magnetism, Electricity and Galvanism, in all their subdivisions, Heat, and Meteorology, within the space of an ordinary middle-sized volume. Of the manner in which the translator has executed his task, it behoves him to say nothing; he has attempted nothing more than a plain and nearly literal version of the original. He cannot, however, conclude this brief introductory note without directing the attention of his Readers to the splendid manner in which the Publisher has illustrated this volume.

E. C. O.

LONDON,
AUGUST 1847.

TABLE OF CONTENTS.

SECTION III.

OF MOTION AND ACCELERATING FORCES.

CHAPTER I.

CHAPTER II.

CHAPTER III.

SECTION IV.

ACOUSTICS.

CHAPTER I.

CHAPTER II.

CHAPTER III.

SECTION V.

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

CHAPTER V.

CHAPTER VI.

SECTION VI.

MAGNETISM AND ELECTRICITY.

PART I.—MAGNETISM.

CHAPTER I.

CHAPTER II.

PART. II.—ELECTRICITY.

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

CHAPTER V.

PART III.—GALVANISM.

CHAPTER I.

CHAPTER II.

PART IV.—ELECTRO-MAGNETISM.

CHAPTER I.

CHAPTER II.

PART V.

SECTION VII.

OF HEAT.

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

CHAPTER V.

SECTION VIII.

METEOROLOGY.

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

PRINCIPLES

OF

PHYSICS AND METEOROLOGY.

INTRODUCTION.

General Idea.—The grand spectacle that is ever present to our eyes in the vast realm of nature excites within us so ardent a thirst for knowledge, that we feel ourselves irresistibly impelled to the consideration of the combined causes that have produced these wondrous results. Such subjects fall within the department of natural philosophy, whose task it is to trace the connecting link between the different phenomena of nature, and, as far as this is possible, to unravel the causes from which they have originated.

The combined natural sciences treat of *bodies*—a word which we must not receive in the limited sense in which it is understood by the mathematician, who looks only to the relations of space, disregarding the matter that fills space; while it is to the properties of this very matter that the natural philosopher devotes his especial attention. The interior of bodies is closed to our view, their external appearance being only made known to us by means of what we learn concerning them through our senses. Thus, a body, standing in no connection with our senses, has, so far as we are concerned, no existence; and it is probable that there is still much passing around us in nature of which we have no conception, from the want of some additional sense by which we can recognise its existence.

The province of the natural sciences is, therefore, to trace the connection existing between the phenomena brought within the scope of our knowledge by means of the senses, and so to arrange

them, that they may elucidate each other, and manifest the mutual dependence existing between them. If we are able to trace a phenomenon in its connection with other phenomena we have explained it; and a natural law is obtained as soon as the unchangeable link of connection existing between the natural phenomena is understood, even should we still remain ignorant of the final cause.

Division.—The vast department of the natural sciences divides itself into two great branches—Natural History and Natural Philosophy. The former teaches us to know the nature of individual objects, and arranges them in systems according to their different characters; while the latter endeavours to lay open the natural laws of the material world.

By the term *physics*, we understand that branch of the natural sciences which treats of phenomena which do not depend upon a change of the constitution of bodies; the latter falling under the head of *chemistry*.

As may be readily conceived, it is not always easy to trace with accuracy the line of demarcation between these two sciences. They are most intimately connected with each other, in some measure even forming one whole, which appears to have been divided chiefly owing to its embracing so wide and increasing a field of observation.

Method.—We must now point out the manner in which the student may attain to a knowledge of the laws of nature, and by what means the facts already ascertained have been acquired. The sources of knowledge, as well as the methods of acquiring it, are not and cannot be the same for all sciences. The mathematician may, starting from his own self-acquired conceptions, develop his science wholly out of himself; and we might even conceive the possibility of a man shut up within four walls, and separated from all communication with the outer world, constructing the whole science of mathematics from his own ideas of space and number.*

* [We find the same idea expressed in nearly the same words in Herschel's beautiful Essay "On the Study of Natural Philosophy:"—"A clever man, shut up alone, and allowed unlimited time, might reason out for himself all the truths of mathematics by proceeding from those simple notions of space and number, of which he cannot divest himself without ceasing to think. But he could never tell by any effort of reasoning what would become of a lump of sugar if immersed in water, or what impression would be produced on his eye by mixing the colours yellow and blue." P. 76.]

Seen from this point of view, mathematics is a purely speculative science, the very reverse of natural philosophy, which treats of objects that solely and alone come to our knowledge through the perceptions of sense and in the course of experience.

The ancients were wholly unacquainted with any science of natural investigation that was based upon experience; and hence their philosophical speculations upon the world in general, and upon the rise and origin of all material objects, are nothing but confused conjectures, and possessed of little value, frequently, indeed, standing in direct opposition to fact and experience.

Even in the middle ages the natural sciences were not much more developed, partly because the human mind was directed in other channels, and partly because the Aristotelian philosophy was held in such high esteem that all inquiries and progress were alike checked.

Galileo was the first to enter the path of practical experiment, and Bacon showed that there was no other road that would lead to a knowledge of the laws of nature.

The only source from whence we can draw our knowledge of nature is the perception of the senses,—practical experience,—observation. Hence we derive the materials which must be united and worked into a science by our mental activity.

We derive our scientific perceptions either from changes effected by nature itself, or we designedly place bodies in those conditions that may call forth certain phenomena. In the first case we make observations; in the second, experiments.

By means of good observations, and judiciously-conducted experiments, we learn to know the external connection of the phenomena of nature. And this connection is what we term a natural law.

By the aid of experiments we may arrive at a knowledge of these laws, even while we remain wholly unacquainted with their internal connection, and with the nature of forces.

The law of the refraction of light was known long before any correct idea was formed as to the nature of light; and, in the present day, we know the laws of the distribution of electricity, but we have little or no knowledge concerning the nature of electricity itself.

It is only the external connection of things that can be discovered by perception; and we can hazard nothing more than hypotheses as to the internal causes of phenomena, or the origin of the forces

from which they are educed. These hypotheses are like questions which we put to Nature, but the answers she gives are not simply "yes" and "no;" but it can be so, or it cannot. Nevertheless, from these hypotheses deductions may generally be drawn which can subsequently be confirmed or refuted by further observations. In proportion to the number of facts that can be explained by help of an hypothesis, and the more we can confirm it by new observations, the greater probability does it acquire.

In all branches of physics we shall find examples of, and evidence favouring the correctness of these views.

SECTION I.

GENERAL PROPERTIES OF BODIES.

As PHYSICS treat of bodies, it is most essential to form to oneself a representation of the nature of these bodies, and this object is the most readily attained by the consideration of those general properties which we observe to exist in all bodies, whatever other differences they may manifest.

Thus, it is essential to the existence of a body that it occupy a limited space, possess the property of extension, and that no other body occupy the same space at the same time; this latter condition indicating the property of impenetrability. Besides these two properties, without which we can form no conception of matter, we observe other general properties, as divisibility, extensibility, compressibility, porosity, inertia, and gravity.

Divisibility.—As far as our experience goes, we find that all bodies are divisible; that is, they may be divided into smaller and still smaller particles. Here the question arises:—What are the limits of this divisibility? And again:—Do we by continued reduction arrive at particles which, although still perceptible to the senses, are incapable of being further divided? Experience furnishes us with the reply, that divisibility continually oversteps the limits of sensible perception. As an instance of extreme divisibility we may adduce musk, which will continue year after year to fill an apartment with the most intensely-penetrating odour, without any perceptible loss of weight.

Chemically, compound bodies afford the best evidence that divisibility passes the limits of sensible perception. In cinnabar, for example, which is composed of mercury and sulphur, and may easily be separated into these constituents, we are unable to distinguish small particles of sulphur and mercury from one another; even under the best microscope it appears to be a perfectly homogeneous mass.

But, although divisibility extends far beyond the limits perceptible to sense, it must not be assumed that it is wholly unlimited; for to adopt such an assumption were, in other words, to admit that the size of the ultimate undivisible particle is null, while it is evident that, if the ultimate particle have no extension, it cannot enter into the composition of an extended body.

It is upon these considerations that the natural philosopher bases the hypothesis that all bodies are composed of minute particles, which cannot be further disintegrated, but are undivisible, and therefore termed atoms.

This fundamental view of the constitution of bodies is now universally embraced by the natural philosopher, and the chemist, as the atomic theory.

In speaking of small particles, without actually wishing to designate them as ultimate portions or atoms, we generally make use of the term molecules, which is synonymous with particles of a mass.

Extensibility and Compressibility.—A second general property is extensibility, on which depends compressibility. The same body does not always possess a similar volume, since it may be diminished by pressure and cold, and enlarged by expansion and heat. If, then, we assume that the atoms are invariably the same, we can only explain extensibility on the hypothesis that the atoms are not in immediate contiguity with each other, but are separated by interstices, according to the enlargement or diminution of which the volume of the body changes.

Porosity.—The interstices which occur between the different particles of bodies are named pores; and, if we apply the same term to the interstices between the atoms of bodies, it is evident, from what has been already stated, that every body is porous, and that porosity is therefore a general property. In common speech, however, we understand by the term pore an interstice sufficiently large to admit of the passage of fluids and gases; and, according to this definition, porosity is certainly not a general property. A sponge, all artificial textures—chalk, pumice, &c.—are porous in the restricted sense of the word.

Different Nature of Atoms.—After developing the fundamental idea of the atomic theory by the consideration of divisibility and extensibility, we will pass to the observation of the mode in which different bodies are formed from atoms, and next consider the remaining common properties of matter.

We find that there are in nature a number of bodies, the properties of which are so different that we must necessarily assume that the atoms of which they are composed likewise differ in their nature. If, for instance, we consider sulphur and lead, we find that the relations of these two bodies are remarkably different, a fact which can only be explained by the hypothesis that the atoms of sulphur are not of the same nature as those of lead.

Most bodies are not composed of homogeneous parts, but of such as differ among themselves, even where they appear to be of like nature, as we mentioned in the case of cinnabar, which is composed of sulphur and mercury; and as in water, which we find to be a compound of oxygen and hydrogen; and in common salt, which is composed of chlorine and sodium. Bodies such as these are said to be chemical compounds, in contradistinction to those which are not capable of being decomposed into different constituents, and which are, therefore, called simple bodies, or elements. There are fifty-five or six of such simple bodies or elements, which hitherto at least have not been found to admit of further decomposition. The consideration of these elements, and of the mode in which they enter into the composition of other bodies, falls within the province of chemistry.

Aggregate Conditions.—In addition to the above differences of bodies, we observe others, which depend, not upon a difference in their constituent parts, but upon the manner in which the particles are united. Thus one and the same substance may assume totally different forms, as water, which is solid when it appears as ice, fluid as water, and gaseous as steam. Without changing its composition, we may convert water into ice, and ice into water—vaporize water, and again condense it.

All bodies with which we are acquainted are in one of these three conditions, either solid, fluid, or gaseous (aëriform).

Solid bodies have, independently of the slight changes effected on them by heat, a constant volume and an independent form; and it requires a greater or lesser amount of force to divide a solid body. Thus it is impossible to compress a piece of iron to the half or the third of its volume, or make it fill a space twice or three times as great as it occupies, it being only by extreme force that we are enabled to change its form or to divide it.

Fluids have, in the same sense as solid bodies, a constant volume; that is, although they may be slightly compressed by strong pressure, or somewhat expanded by the action of heat, the

change of volume thus induced is very inconsiderable. We cannot compress the water which fills a quart bottle into a vessel of half the size, and, if we pour the fluid into one of twice the bulk, the vessel will only be half filled. But fluids differ from solid bodies in having no independent form, the figure they assume being that of the vessel containing them, the surrounding solid body, while the liquid presents a horizontal surface where it intersects the sides of the vessel. Fluids also differ essentially from solid bodies in the least imaginable force being sufficient to separate their particles.

Gaseous bodies have neither an independent form nor a definite volume; the space which they occupy depending only upon external pressure. A volume of air may easily be reduced to the half, the fourth, or even the tenth of its original bulk; and, conversely, we find that, on admitting the same volume of air into a vacuum twice, four times, or ten times as large, the air will completely fill it, thus proving that gaseous bodies have a tendency to expand as far as possible. Easy divisibility is alike common to gases and fluids.

The external differences must, according to our views of the composition of bodies, depend upon the circumstance that in solid bodies the individual particles remain at certain distances from, and in fixed relative positions to, each other; in fluids they remain at fixed distances, but may easily be displaced; while in gaseous bodies the component parts show a constant tendency to separate.

Molecular Forces.—As a force is necessary to separate the particles of a solid body, and as also an external force is necessary to hold together the particles of a gaseous body, it is clear that bodies cannot be formed by means of a simple juxtaposition of their atoms, since they would then be nothing more than an unconnected mass somewhat in the condition of a sand-heap. There must, consequently, be forces which hold together the particles of a solid body in their relative position, imparting to them a fixed internal structure and external form; and in like manner there must be forces which act repulsively amongst the particles of a gas. These forces, which are continuously acting between the adjacent molecules of bodies, are termed molecular forces. The force which holds together the particles of a solid body is termed the force of cohesion, which we assume to be called forth by a mutual attraction of the atoms. Now, if atoms mutually attract each other, it is not easy to understand how these can also mutually repel each other, and, therefore, in order to explain this repulsion

observed in gases, we assume that there is another and an opposite force, which we term the force of expansion.

Solid bodies may be melted by heat; that is, they may be transformed into a fluid condition; and through the same agency fluids may be reduced to the state of vapour; it follows, therefore, that heat is opposed to the force of cohesion, and hence we may assume it to be identical with the force of expansion. Let us suppose the molecules of a body to be surrounded by an atmosphere of heat which modifies the attraction of the molecules, and we shall then understand how the attractive and the repulsive forces proceed from one common centre. The preponderance of the expansive or of the repulsive force will determine whether a body be solid or gaseous, while an equilibrium of both forces characterizes a fluid.

Inertia.—Throughout the whole kingdom of nature no change in the condition of things can occur without a special cause. Thus whatever change may occur in a body, whether it be relating to rest or to motion, or to a change in its aggregate condition, must be occasioned by some force. If a body be at rest, a force is necessary to put it into motion, and, conversely, it cannot be reduced to a state of rest from motion without the agency of some force, for a body once put into motion, will continue that motion with unchanging velocity, in an unchanging direction, until its course be arrested by external impediments. This property of a body we term inertia.

We find numerous examples in every-day life elucidating this law of inertia. Thus the wheel of an engine continues to pursue its course after the force which impelled it has been arrested, and it would continue to run on for ever if the motion were not constantly impeded by friction.

In running fast the speed cannot suddenly be checked. A man standing upright in a boat will fall backwards when the boat is pushed from the shore, and will be urged forward as the boat touches the land. We shall subsequently have frequent opportunities of alluding to the influence of the law of inertia upon many phenomena of motion. According to the law of inertia, a body must exercise a resistance against every force which removes it from a condition of rest to one of motion; or which hastens, impedes, or tries wholly to arrest it when in motion. It is, therefore, clear, that the action exercised upon the condition of motion of a body must depend on the one hand upon the intensity

of the force, and on the other upon the degree of inertia in the body.

The larger the quantity of matter—that is to say, the greater the mass is on which a force acts—so much the greater will be the resistance it offers; and we judge of the mass of a body by the amount of resistance which it can oppose by its inertia to an accelerating or retarding force. This idea of inertia and mass cannot be rendered very clear until we have occupied ourselves somewhat with the study of the laws of gravity and motion.

Gravity.—If we remove a piece of stone or wood from the ground and throw it from our hands it will, when left to itself, fall until it reaches the earth, or meets with any object to arrest its course. As matter is inert, it cannot of itself pass from a state of rest into one of motion. If, then, we see that a body in rest begins to move at the same moment that we deprive it of its support, we must ascribe this to a force, and to this force we apply the term gravity.

Gravity is, therefore, the force which compels bodies to fall. We must not, however, suppose that its power is limited to this action, for we shall soon see that gravity produces other phenomena, and other motions. The direction of rivers which flow into the sea, the rising of a piece of cork from the bottom of the water to the surface, the ascent of the air-balloon, are all the effects of this force.

There is no better means of ascertaining the direction of the force of gravity than the following:—Fasten a string at one extremity, and attach a small heavy weight at its other extremity, the direction of the thread, when it is tense and at rest, will determine with accuracy the direction of gravity. This little instrument is called a plummet, and the line which the thread forms in a state of equilibrium is the vertical. The direction of gravitation is therefore identical with that of the plummet, and nothing can be easier than at all times, and in all places, to ascertain this direction of gravitation. As we shall see when we treat of hydrostatics, the upper surface of every fluid at rest must be at right angles with the direction of gravitation, or we may express the same thing differently by saying that the direction of gravitation is always at right angles with the earth's surface. Here, as may easily be supposed, we do not speak of the true surface of the earth with its hills and valleys, but of an ideal surface, of which we must form a conception in the

FIG. 1.

following manner:—If we assume that the Atlantic Ocean, the South Sea, and all other seas, were for a moment perfectly at rest, then their vast superficies would form a part of a spherical surface; and if, further, we assume that the different parts of this surface were spread under the surface of the land, still retaining their curvature, they would form a spherical surface without hills or valleys. This partly imaginary and partly actual surface is what we term the level of the sea—the horizontal line. When, therefore, we say that Mont Blanc is 14,690 feet above the level of the sea, we mean that a perpendicular dropped from the summit of the mountain must measure 14,690 feet in order to reach this ideal surface. In Holland there are whole districts below the surface of the sea; that is to say, this imaginary level is at an elevation above the heads of the inhabitants.

The force of gravity is always directed towards the central point of the earth, as we perceive from what has been already stated. The directions of the plummet at two different parts of the earth are, consequently, not parallel, for they make a certain angle with each other, the point of which coincides with the central point of the earth. Berlin and the Cape of Good Hope are two places lying in nearly the same meridian line. Berlin is $52^0\ 31'\ 13''$ north of the equator, and the Cape of Good Hope $33^0\ 55'\ 15''$ south of the same line; and if we draw two lines towards the central point of the earth, the one from Berlin and the other from the Cape, we find that they make an angle of $86^0\ 26'\ 28''$, being the angle which the plummet at Berlin makes with the plummet at the Cape. If the experiments be made at two points lying within the circumscribed space of an apartment, or even at the extreme ends of a city, no deviation in the direction of the plummet will be perceived; the reason of which is, that the central point of the earth (the focus towards which the two lines incline) is distant from the surface of the earth more than six millions of metres* (the radius of the earth). Now, as 200 metres scarcely compose the 30,000th part of the earth's radius, it follows that two plummets placed at the distance of 200 metres from each other would form an angle of about 6.3 seconds. If the places at which the experiment is attempted were less removed from each other the angle would cease to be appreciable.

If a body be impeded in its fall by the intervention of some

* The metre is equal to 39.37 English inches.—Tr.

other supporting body, the action of the force of gravity does not cease, but manifests itself in this case by pressure upon the intervening object.

Gravity is a general property of bodies; that is, it is common to fluids and gases, as well as to solid bodies. The falling of the rain drop proves the gravity of fluids, and we shall subsequently adduce instances of the gravity possessed by gaseous bodies, and consequently show that the whole atmosphere surrounding our globe presses upon the earth's surface.

Weight.—The amount of pressure exercised by a body upon another body upon which it rests is called its weight, this pressure increases with the number of material particles of the body. In order to compare the weight of different bodies, we make use of the balance, the application of which is familiar to all, and its arrangement we shall describe subsequently.

In France the gramme is the legal *unit* of weight, and at the present day it is received almost universally as the *unit* measure in scientific researches. The gramme is the weight of a cubic centimetre of pure water in its state of greatest density. The French system of weights has this great advantage over others, that the units of weight and measure stand in a simple relation to each other, so that it is easy to judge of the weight of a body by its size, and *vice versâ*.*

* A Measure can only be considered as unalterably fixed when it has been derived from some undeviating size or space in nature, as is the case with the French system of measures. Thus any certainty other systems now possess has been derived from a comparison with the system established in France.

The undeviating length which has become the standard for this system is the earth's meridian—that is, the circumference of a large circle of the globe, passing through both poles. The forty millionth part of this line is a metre.

The length of a meridian of the earth was ascertained by a series of the most carefully-conducted measurements, and for this purpose the old French unit of measure — the toise — was used for a basis; it was in this way accurately determined how many of these toises were contained in the earth's meridian, and consequently what was the exact length of the toise. As, however, it was resolved that an entirely new system of measures should be established, the forty millionth part of the earth's meridian, expressed in toises, was taken as the new unit of length—in short, the relation of the metre to the toise was then accurately determined.

As in the present day the French system of measures is referred to in almost all scientific works, we deem it desirable to give a table of the relations of foreign and English weights to those established in the French system, giving by way of introduction, a few facts referring thereto.

The metre is divided into 10 decimetres, 100 centimetres, and 1,000 millemetres.

Mass.—According to the above explanation, the mass of a body is the quantity of matter of which it is composed; and on this quantity depends its inertia; consequently, the amount of this inertia gives the actual measure of the mass, and here gravity furnished us with the best means of ascertaining the quantity we seek.

The mass of a body is always proportional to its weight. This connection between the two is everywhere demonstrable by experiment, although we may readily conceive it to be not a necessary result. For, let it be assumed that there are bodies in nature on which gravity exercises no power, on this account they will not, therefore, the less continue to possess inertia; further let it be assumed that the force of gravity acts unequally upon the particles of different substances, and that a ball of

---

The following diagram represents a decimetre, with its subdivisions, as accurately as we can represent them :—

FIG. 2.

The relation of the most important measures of length to the metre are given in the following table ;—

1 English foot	=	304,79 millimetres.
1 Rhenish or Prussian foot	=	313,85 „
1 Vienna foot	=	316,10 „
1 Paris foot	=	324,84 „
1 Toise = 6 French feet	=	1,94904 metres.
1 German or geographical mile	=	7407 „
1 English nautical mile = 1 Italian mile	=	1852 „

The measures for solid and fluid bodies and the weights are all derived from the measure of length in the French system. Thus the unit of the fluid measure is the litre = 1,000 cubic centimetres. A cubic centimetre of water weighs 1 gramme (or 15,44 grains troy); 1,000 grammes make 1 kilogramme; 1 litre of water, therefore, weighs 1 kilogramme.

One gramme is equal to 10 decigrammes = 100 centigrammes = 1,000 milligrammes.

The pound weight differs considerably in different countries, but it may on an average be said to correspond pretty nearly with the half kilogramme. The Baden and Hesse pound is exactly this weight, as the system of measures adopted in these countries has been derived from the French. This pound of 500 grammes is the standard measure used in the German Zollverein, or general customs.

1 London pound (troy weight)	=	373,202 grmes.
1 Vienna pound (trade weight)	=	572,880 „
1 Old French pound	=	489,506 „
1 Prussian pound	=	467,711 „

lead is only heavier than a ball of wood of equal size because gravitation acts more especially upon the particles of the lead, without, on that account, the mass of the leaden ball being greater than that of the wooden ball. Again, to make the subject clearer, let us suppose two equally large balls, one of lead, the other of wood, and let us assume that the mass or amount of inertia be the same in both, it clearly follows that in this case the leaden ball would fall with the greater velocity, for we know that it weighs some twelve times more than the wooden ball, and that, consequently, the force which impels the former is twelve times as great as that which acts upon the latter, and would, therefore, induce greater velocity if equal resistance were opposed to both balls. We find, however, that the leaden ball falls no faster than the wooden one, at least *in vacuo*, and hence we see that the force which impels the former, although twelve times as great, acts against a body possessing twelve times the inertia of wood. And, as we find that the rapidity with which all bodies fall *in vacuo* is equal, we conclude, on the same grounds, that the mass of a body is always proportionate to its weight, and that, therefore, the weight of a body is a measure of its mass.

Density.—The density of a body is the relation of its weight to its volume, and thus conveys the idea of specific gravity which is a constant characteristic property of every substance. As it was necessary to choose one body in particular as the unit of density, to which all others might be compared, water in its condition of greatest density has been made choice of for this purpose. The density, or specific gravity, of a body is, therefore, the number which indicates how much heavier a body is than an equal volume of water. A cubic centimetre of iron weighs 7.8, a cubic centimetre of gold 19.258 grammes, while an equal volume of water weighs only one gramme; therefore 7.8 is the specific weight of iron, and 19.258 that of gold. Hence to find the specific gravity of a body, we divide its absolute weight by the weight of an equal volume of the water.

Thus the data necessary to determine the specific gravity of a body are its absolute weight by the weight of an equal volume of water.

These data are most readily obtained for fluids. If we take a narrow-necked vessel and fill it up to a certain marked line on the neck, first with water, and then with the fluid to be

determined, and weigh it each time in a balance, we obtain the relative weight of the two fluids. Thus, if we wish to ascertain the specific gravity of oil of vitriol, we must first place the empty bottle on one scale and counterbalance it, then fill it to the graduated line with water. If we assume that the bottle contain exactly one litre, that is 1000 cubic centimetres, the water will weigh exactly 1000 grammes. If, now, we fill the bottle to the same point with oil of vitriol, it will require 1848 grammes to make the balance even. Since the oil of vitriol in the flask weighs 1848 grammes, while an equal volume of water weighs only 1000 grammes, the specific gravity of the former is $\frac{1848}{1000} = 1.848$.

Owing to the difficulty of always obtaining sufficiently large quantities of the fluids to be weighed in so capacious a vessel, and the damage to a fine balance in supporting such heavy masses, it is more expedient to make use of smaller vessels. The form commonly employed is represented in Fig. 3. This vessel is made to contain from eight to twenty cubic centimetres, and has a ground glass stopper made of a part of a thermometer tube, in order to admit of the rising of portions of the fluid in case of expansion by heat through the slender opening without the stopper being raised, or the bottle burst.

FIG. 3.

In order to determine the specific gravity of solid substances we must form from them a body of regular shape, as a cube or sphere, in order to estimate the more readily its cubic contents. The absolute weight of such bodies is found by the balance, and the weight of an equal volume of water is given by the known volume of the body. If a cube of marble weigh, for instance, 21.6 grammes, and each of its sides be two centimetres, its cubic contents will be eight cubic centimetres; a cube of water of like size will thus weigh eight grammes; and, consequently, the specific gravity of the marble is to that of water as $\frac{21.6}{8} = 2.7$.

Take a sphere of dried beechwood weighing 25.79 grammes, and, supposing its diameter to be four centimetres, we may easily compute its cubic contents, which we shall find to be 33.49 cubic centimetres. A sphere of water of equal size will, therefore,

weigh 33.49 grammes, and the specific gravity of the wood is therefore, $\frac{25.79}{33.49} = 0.77$.

As, however, it is not always possible to obtain such large quantities of substances, and it is sometimes impracticable to form bodies of the regularity of figure necessary, other methods must be resorted to for ascertaining the specific gravity; and the majority of these depend upon hydrostatic laws, the consideration of which we must postpone to a subsequent period. The following method, however, is not grounded upon these principles, and is often made use of to ascertain the specific gravity of such bodies as can only be obtained in small portions.

We first fill the vessel (Fig. 3) with water, and bring it into equilibrium in the balance, then lay the granules beside it, and ascertain the absolute weight. This done, we remove both from the scale, and, throwing the granules into the water in the bottle, again insert the stopper. A quantity of water will then escape, equal in bulk to the granules which have displaced it. On weighing a second time, we strain the quantity of water that has been displaced; or, in other words, the weight of a volume of water equal to the volume of the granules.

By way of illustration, let us determine the specific gravity of platinum granules as they occur in nature:—

The glass vessel with water weighs . .	13.52	grms.
The granules	4.056	„
Both together	17.576	„

If, after throwing the granules into the bottle, putting the stopper on, and weighing the whole together, we find it to be 17.316 grammes, the weight of the water forced out by the granules must be 17.576—17.316 = 0.26 gram.; consequently the specific gravity of the granules is $\frac{4.056}{0.26} = 15.6$.

The same method may be pursued with larger portions of bodies if a suitable vessel be chosen for the experiment.

If the body to be weighed be soluble in water, some fluid must be chosen, as alcohol, oil of turpentine, or some other in which the body does not dissolve. By the above-described process, we find how much a certain quantity of the fluid weighs which has the same volume with the body to be weighed, and, when once

the specific gravity of the fluid is known, it is easy to ascertain the weight of an equal volume of water.

Let it be assumed that a piece of salt which is insoluble in oil of turpentine weigh 0.352 gram., and displaces when put into the glass 0.13 gram. of oil of turpentine. The specific gravity of this fluid is 0.8725; an equal volume of water will therefore weigh $\frac{0.13}{0.8725} = 0.149$, and the specific gravity of the salt is, therefore, $\frac{0.352}{0.149} = 2.36$.

SECTION II.

EQUILIBRIUM OF FORCES.

CHAPTER I.

EQUILIBRIUM AND DECOMPOSITION OF FORCES IN THE SO CALLED SIMPLE MACHINES.

A BODY is in a state of equilibrium when all the forces acting upon it counteract each other, or when their action is prevented by any resistance. In a body suspended by a thread, the action of gravity is destroyed by the resistance of the thread. If the thread be not strong enough, it will break, and the body will fall to the ground. A body may often be in equilibrium without having any fixed point of support, and without any apparent resistance. The fish may be in a state of equilibrium in the water, and the balloon in the air, but here the gravity is counteracted by a pressure, of which we shall further speak.

It may be said that all bodies which appear to be in a state of rest are acted upon by many mutually counteracting forces. It falls to the department of statics to ascertain the conditions of equilibrium, while the subject of dynamics, on the other hand, investigates the laws of the motions which result when the conditions requisite for the establishment of equilibrium are not satisfied.

In order to measure forces we must assume some arbitrary force as unity.

Two forces are equal when, in acting upon one point from opposite directions, they remain in equilibrium. Two equal forces acting in the same direction are equal to a double force. We should have a triple force if three equal forces acted in the same direction, and so on.

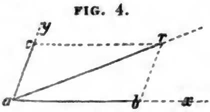
Whatever be the number of forces acting upon one point, and whatever their direction may be, they can only impart one single movement in one definite direction. Hence we assume that there is a force which is capable in itself of producing the same action as these combined forces, and consequently of replacing them. This is termed the resultant. For example, when a ship is impelled by the combined action of the stream, the rudder, and the wind, it moves in a definite direction; but if the actions of the stream, rudder, and wind were to cease, we could evidently impart the same motion to the vessel by attaching to it a rope or line by which a definite force might be made to bear in the direction towards which the ship was impelled by the simultaneous action of the three forces. This, then, is the resultant of the three forces.

The combination of forces which act together upon one point, we term a system of forces, or, when speaking of them in reference to the resultant, we call them component or lateral forces. It is evident that, if we were to add to the combined system of forces a new force, equal and opposed to the resultant, all the forces acting in concert must retain their equilibrium. If, for example, to abide by our former illustration, we had caused a force to act upon the line of the vessel which was equal, but opposed, to the resultant force of the stream, rudder, and wind, the newly-applied force would induce a state of equilibrium, and the ship would remain at rest just as if it were lying at anchor.

If two or more forces act in the same direction their resultant is the sum of the separate forces. When two forces act in opposite directions upon one point, the resultant is equal to the difference of the two, and will act in the direction of the greater.

If the directions of two forces acting upon a material point make an angle with each other, we find the resultant by means of a law known under the name of the parallelogram of forces, and established by means of the following simple consideration:—

FIG. 4.

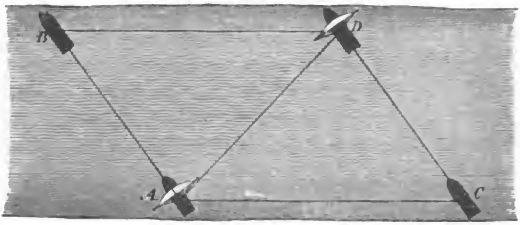


Suppose two forces acting simultaneously on the point *a*, one in the direction *a x*, the other in the direction *a y*. Let one force be such that in a given time—say a second—it will by itself move the point from *a* to *b*, while the other force will, in the same period of time, move it by itself from *a* to *c*. If

now the point be exposed for a second to the simultaneous action of both forces, the effect is evidently the same as if the point were subjected for one second to the sole action of the one, and the next second to the sole action of the other force. The first force alone impels the point from *a* to *b* in one second; and if the action of this force were to cease at the instant the point reaches *b*, and the point be then solely subjected to the action of the second force, it would, at the close of another second, reach *r*. Hence, if both forces act simultaneously, the point *a* must, in the course of a second, reach the same point *r*.

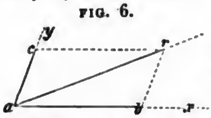
An illustration will make this more evident. A ship acted upon

FIG. 5.



simultaneously by two forces, the stream and wind, starts from the point A on the side of a river. Let us assume that the vessel will be urged obliquely across the river by the action of the wind alone, in a definite time, say a quarter of an hour, going from A to B, and assume it to be borne during the same period of time by the force of the stream alone; if there were no wind from A to C, then it would in the same period of time go from A to D, if both wind and stream acted simultaneously, that is, it must reach the point D in a quarter of an hour, when impelled by the simultaneous action of the two forces, as it would have gone from A to B in a quarter of an hour, if acted upon solely by the wind, and from B to D during the next quarter of an hour when impelled only by the stream.

FIG. 6.



The line *a r* (Fig. 6) is the diagonal of the parallelogram *a b r c*, which by means of the law we have mentioned may be thus expressed.

The resultant of two forces which simultaneously act at any

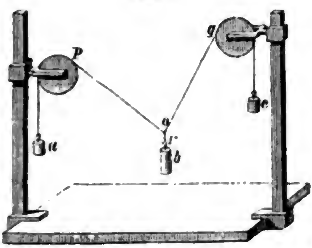
angle upon a material point is such as to tend to move the point through the diagonal of the parallelogram, which we may construct from the lines corresponding to each of the component or lateral forces.

As the line which a body passes over in a given time is proportionate to the force which impels it, and as in determining the resultant we only endeavour to find its direction and relations of size to both component forces, the law may be thus expressed:—"If two lines be drawn in the direction of two forces, and through their point of contact and their length to be proportionate to the respective forces, the diagonal of the parallelogram which is determined by these two lines will represent the resultant both in magnitude and direction."

As a state of equilibrium must be established between three forces, if each be equal and opposed to the resultant of the other two, we may easily, by means of an experiment pertaining to statics, test the correctness of the law of the parallelogram of forces.

To the leaf of a table there are attached two vertical rods, each of which has a moveable slide bearing a pulley that turns easily upon its axis in a vertical plane. The rods must be so screwed on that the vertical planes of both pulleys coincide. If now we have a line over the pulleys, attaching at one end a weight *a*, at the other end a weight *c*, and lastly, a weight *b* between the pulleys, the whole will be in a state of equilibrium in any definite position of the threads; we have three forces acting upon the point *o* in the directions *o p*, *o q*, and *o r*, and it is easy to ascertain whether those relations between the amount and direction of the forces really exist, such as the law of the parallelogram of forces requires.

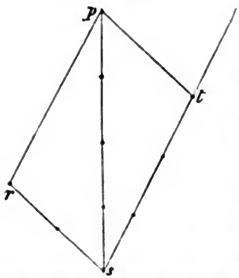
FIG. 7.



Supposing by way of illustration, that $a = 2$ and $c = 3$ ounces, how great must be the force at *b* if the angle *p o q* be 75°? According to the above law the resultant may easily be obtained, by construction, as in Fig. 8.

If the angle *r s t* measure 75°, and $r\ s = 2$ and $s\ t = 3$ (some unit being assumed), we shall find that the diagonal $s\ p = 4$. Thus, if the angle $p\ o\ q = 75°$, the weight

FIG. 8.



b must be equal to 4 ounces; and if we attach a weight of 4 ounces to the string, we shall find that the angle $p\ o\ q$ will measure 75^0; and this we may easily prove by holding a figure of larger dimensions behind the thread, $r\ s$ corresponding with $o\ p$, and $s\ t$ with $o\ q$. If b had been made larger than 4, and all the other parts of the figure were left unaltered, the angle $p\ o\ q$ would be less than 75^0; and the smaller we make the weight at b, the larger will be the angle $p\ o\ q$.

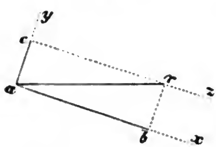
When both forces are equal, the resultant divides the angle which they make with each other into two equal parts.

When the two forces are unequal, the resultant divides their angle into unequal parts, approaching more nearly to the direction of the larger force.

As we can find the resultant of two forces acting upon a point, so it is likewise easy to ascertain the resultant of any given number of forces, nothing more being necessary than to find the resultant of the two first forces, then their resultant with the third force, and so on.

As two forces can be replaced by a single force, so, conversely, we may substitute two forces for one; and we see further, that an infinite number of different systems of forces may have the same resultant, and conversely, that one force may be replaced in innumerably different ways by a system of two forces. But if it were required that the force $a\ r$ should be replaced by two other forces, one of which should have the direction $a\ y$, and the magnitude $a\ c$, the problem is perfectly definite, there being but one way to complete the parallelogram, and to find the component or lateral force $a\ b$.

FIG. 9.

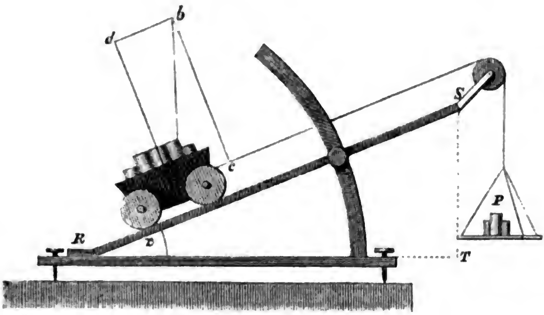


From the parallelogram of forces are derived the laws of equilibrium in all simple machines; and these we now proceed to describe.

The Inclined Plane affords a practical illustration of the decomposition of forces. When a weight rests upon a plane, which forms an angle x with the horizon, the gravity of the body acting

in the direction *a b* is no longer at right angles to the plane, and, consequently, the latter has not to support the full pressure of the

FIG. 10.



weight of the load. In fact, the gravity of the body may be decomposed into two forces, the one of which acts at right angles with the plane, causing the pressure, while the other, acting parallel with the inclined plane, urges the body down it. The magnitude of these two forces may easily be obtained by construction. If *a b* represent the magnitude and the direction of gravity, we have only to draw a line at right angles with the inclined plane through *a*, and another parallel with it, then join *b* and *d*, and drop the perpendicular *b c*. The line *a d* represents the amount of pressure which the plane has to support, *a c* the amount of force which impels the load down the inclined plane, or, in other words, the pressure upon the plane, and the force which tends to move the body parallel to the inclined plane are to the weight of the body as the lines *a d* and *a c* are to *a b*.

But the triangle *a b c* is similar to the triangle $R\ S\ T$ and $a\ b : a\ c = R\,S : S\,T$, and, consequently, the force which urges the body down the inclined plane is to its weight as the height of the plane is to its length. If we denote by x the angle which the inclined plane makes with the horizon, then it is evident that $a\ c = a\ b\ sin.\ x$ and $b\ c = a\ b\ cos.\ x$; and, therefore, if P represents the weight of the body, the pressure which the plane has to support is equal to $P\ cos.\ x$, and the force that urges the body down the plane is equal to $P\ sin.\ x$.

We will attempt to make this point clearer by the following illustration. If we lay a load in a little carriage, and

place it upon an inclined plane, it will roll down; this may, however, be hindered by attaching to the carriage a line, passing round a pulley, and having the weight P suspended from its other extremity. Supposing the little carriage and its load to weigh 100 ounces, and the angle x to be 30^0, then $S\ T = \frac{1}{2}\ R\ S$, and, consequently, $a\ c = \frac{1}{2}\ a\ b$; that is to say, the force which urges the carriage down the plane is equal to the half of its weight, and the carriage will, therefore, be prevented from rolling down, if we make the weight P equal to 50 ounces.

If the angle x were $19^0\ 30'$, then would $S\ T = \frac{1}{3}\ R\ S$, and then the weight P need only be $\frac{100}{3} = 33$ ounces to prevent the carriage from rolling down the plane.

As $sin.\ 14^0\ 30'$ nearly $= \frac{1}{4}$, that is to say, when the angle $x = 14^0\ 30'\ S\ T = \frac{1}{4}\ R\ S$, in this case P must $= \frac{100}{4} = 25$ ounces.

In order to make experiments with reference to different angles of inclination, we must use a polished board, which by means of a hinge is so secured to a fixed horizontal board as to admit of being placed at any angle of inclination that may be required. The pulley round which the line is passed may be secured to the board, but we may also easily make use of one of the rods in Fig. 7 for this purpose, as the slide may be pushed up and down to raise or depress the pulley to the elevation required. Instead of attaching the weight P directly on the line, we lay it in a scale which has been weighed, and, together with its contents, must be made equal to the computed weight P.

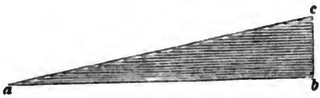
We daily see the practical application of the inclined plane. Every road leading up an ascent is an inclined plane, on which weights are lifted from valleys to the summit of hills; for instance, in order to draw a loaded waggon up a hilly road, besides the force necessary to overcome the friction (which is likewise required upon even ground), we must apply another force to sustain the equilibrium with that portion of gravity acting parallel with the inclined plane, and which increased with the steepness of the road. For this reason it is preferable to make a road winding circuitously round a hill, instead of carrying it directly upward. It frequently happens in erections of almost every kind that the materials for building are raised to the required height by means of inclined planes. This application of the inclined plane was known to the

ancients; and it is highly probable that the Egyptians availed themselves of it in order to raise the huge blocks of stone which they employed in constructing their pyramids.

The Screw is an inclined plane wound round a cylinder. Let *a b c*, Fig. 12, be a rectangular piece of paper whose horizontal side, *a b*, is equal to the circumference of the cylinder, Fig. 11, the paper be so wound around the cylinder that *a b* shall form the periphery of its base, the hypothenuse *a c* will wind round the cylinder in an uniformly ascending curved line, *o p q r;* if the point *a* coincide with the point *o*, *b* will also coincide with *o*, and *c* will be vertically over *o* at *r*. The curved line *o p q r*, which is represented in our figure, is termed the thread of the screw; and its reverse side has been drawn white in order to show the entire curvature of the line from *o* to *r*, is the distance of two contiguous threads.

FIG. 11.

FIG. 12.



If we imagine a triangle continued along the thread of the screw round the cylinder, we obtain a screw with a triangular thread, as shown in Fig. 13; and, if we suppose a parallelogram wound in like manner round the cylinder, we have a flat-threaded screw, as represented in Fig. 14. A screw cannot by itself be applied to remove or lift heavy weights, or to exercise any strong pressure; for to effect these purposes it must be so combined with a screw-box or nut (which is a concave cylinder, on the interior of which a corresponding spiral cavity is cut), that the elevations of the one may accurately fit into the depressions of the other. If we suppose the screw to be fixed vertically, then every revolution must cause an elevation or depression of the nut. If a weight lying in the nut should be raised by the turning of the screw, it is evident that the same principles are at work here, as in an inclined plane of equal elevation. The steepness of the convolutions of the screw is inversely proportional to the distance between two contiguous threads as compared with the circumference of the cylinder.

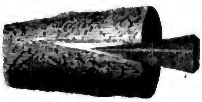
FIG. 13.

FIG. 14.

The screw is used partly to lift heavy weights, and partly to sustain great pressure, the resistance acting in some cases upon the screw itself, and in others upon the screw-box. In estimating the effect of a screw we must not lose sight of the fact that friction plays a conspicuous part in its action; but of this we shall speak presently. In order to make use of the screw as a powerful machine, the turning force is not applied directly to the circumference, but to a lever, or arm, as we may observe in all screw-presses.

The Wedge.—Another form of applying the inclined plane is the wedge, which is used to cleave wood and masses of stone. By thrusting wedges under their keels, ships are raised for the purpose of being repaired in the docks. The wedge is the principal agent in the oil-mill. The seeds from which the oil is to be extracted are introduced into hair bags, and placed between pieces of hard wood. Wedges inserted between the bags are driven by allowing heavy beams to fall on them. The pressure thus excited is so intense that the seeds in the bags are formed into a mass nearly as solid as wood. All our cutting implements, as knives, chisels, scissors, are nothing more than wedges. It must be perfectly clear to every one that the action of the wedge may be referred to that of the inclined plane.

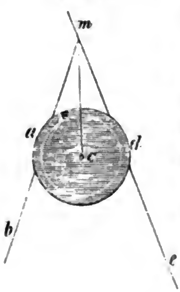
FIG. 15.



The Pulley is a round thin disc, hollowed out on its edges, and turning upon an axis passing through its centre at right angles with its plane.

We divide pulleys into the fixed and moveable. Fixed pulleys are such as have an immoveable axis, and simply allow of things being turned round them. If a string or line be passed round a part of the circumference of a fixed pulley, and forces act at either extremity, a state of equilibrium will not be brought about unless the force which stretches the line on the one side be equal to the force acting on the other. Fig. 16 represents a pulley, *c*, moving round a fixed axis, and the line stretched by forces acting in the directions *a b* and *d e*. If we suppose the lines *d e* and *a b* prolonged to their intersecting point, *m*, it is evident that if *m* were a point connected with the pulley, we could change the points of application of the two forces from *a* and *d* to *m*

FIG. 16.



without altering anything in the action; and thus we should have two forces meeting at *m*, which could only be in equilibrium if their resultant were so. If the two forces meeting in *m*, and acting in the directions *m b* and *m e*, are equal, their resultant will bisect the angle *b m e*, and will then pass through the fixed central point *c*, and we shall have a condition of equilibrium. If one of the two forces be greater than the other, the resultant will no longer pass through the fixed point, and consequently equilibrium will not be maintained.

FIG. 17.

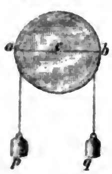
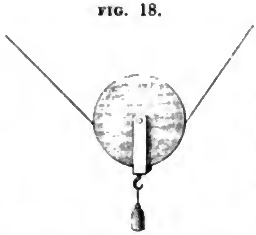


FIG. 18.



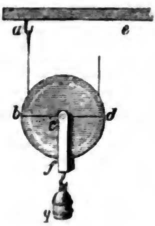
The pressure which the axis of the pulley has to sustain must clearly be equal to the resultant of the two forces; and if the directions of the forces be parallel, as in Fig. 17, the pressure upon the axis is equal to the sum of the two forces, in which we might also include the weight of the pulley.*

A moveable pulley cannot be in equilibrium unless the forces by which the two ends of the string are stretched are equal to one another, for in this case only does their resultant pass through the central point of the disc. The action of this resultant is not arrested owing to the fixed condition of the axis, but owing to there being a third power in the axis in the direction of the resultant, which is equal and opposed to it. This third power is usually applied to a hook fastened on the block. At Fig. 18 it is represented by a weight.

When the two ends of the line passing round the moveable

* It might be objected that this is arguing in a circle; for we have already used the pulley as an experimental illustration of the correctness of the proposition of the parallelogram of forces, and now we derive the conditions of equilibrium in a pulley from the parallelogram of forces. This, however, is not so unreasonable as it may at first sight appear; for, although the conditions of equilibrium between all the forces acting on a pulley can only be understood in all their bearings by means of the theory of the parallelogram of forces, we may easily perceive, even without any knowledge of these laws, that the powers acting on both ends of a string (the tension of the string remaining constant) passed round a pulley must be equal if they are to be in equilibrium; for, as each force tends to turn the pulley in an opposite direction, a state of equilibrium can only be brought about when these forces are equal, as must already have been made evident to all in our illustration in Fig. 7.

FIG. 19.



pulley are parallel to each other as in Fig. 19, it is evident that the force with which each end is drawn is half as great as the weight hanging to the block. When two groups of pulleys, of which the one is fixed, and the other moveable, are so connected by a line that the latter may pass from the one to the other, we have a system of pulleys.

FIG. 20.

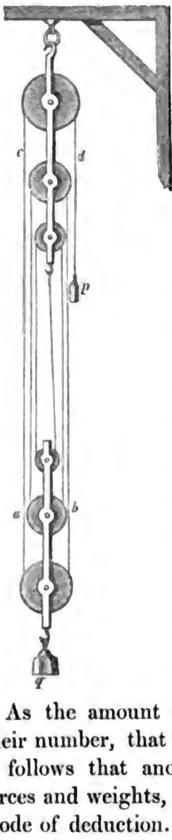


Fig. 20 represents a system consisting of three fixed and three moveable pulleys. The weight q which is attached to the common block of the three moveable pulleys is supported by the six lines which connect the upper and lower pulleys; and consequently, as the weight is equally divided between the lines, each is drawn by one sixth of the weight q; and if sixty pounds weight were suspended to the bottom, each line would be drawn upon by a force of ten pounds.

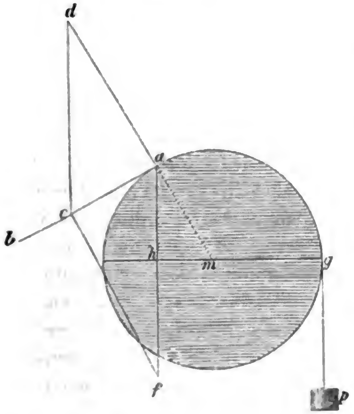
If we observe the external line to the left side which connects the lowest of the moveable pulleys with the highest of those that are fixed, we shall see that this line runs round the top pulley, and hangs freely down on the right side. Now, in order to establish a state of equilibrium, it is necessary that the tension of the line should be equal on the two sides of the upper pulley; and as we have seen that the line to the left is drawn with the force of one sixth of the weight at q, it is necessary to attach a weight equal to one sixth of q to the end of the line, in order to obtain a state of equilibrium. We may, therefore, again poise a weight of sixty pounds, by attaching to the line a weight of ten pounds.

As the amount of weight bearing upon the lines depends upon their number, that is the number of pulleys composing the system, it follows that another relation will be established between the forces and weights, but this can readily be obtained by a similar mode of deduction.

The Lever.—Suppose a line passed round a pulley, to the end

of which the weight p (Fig. 21) is attached; whilst, on the other side, the line is drawn in the direction $a\ b$, with a force equal to the weight p. Here, however, according to the theory of the parallelogram of forces, we may decompose the forces meeting at a, and acting in the direction $a\ b$, into lateral forces, one of which acts in the direction of d from a, being a prolongation of the direction of the radius $m\ a$, while the direction of the other force $a\ f$ is parallel with $g\ p$.

FIG. 21.

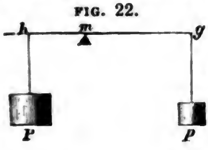


If the pulley be fixed, the action of the force $a\ d$ will be counteracted by the resistance of the fixed central point m; we may, therefore, entirely remove the component force acting in the direction $a\ d$, without disturbing the equilibrium, and we may replace the active force $a\ b$ by its component force acting in the direction of $a\ f$.

If the line $a\ c$ represent the force p acting in the direction $a\ b$, then the line $a\ f$ will give the amount of the component force P, and, without further working out the relations of size between $a\ c$ and $a\ f$ or p and P, we see at once that P must be larger than p; we might, therefore, without disturbing the equilibrium, replace the force p, acting in the direction $a\ b$ by another force P, likewise acting at a, but in a vertical direction.

Instead of letting the force P act directly at a, we may, without disturbing the equilibrium, choose any part of the line $a\ f$ as the point of application; we may, for instance, let the force P act at the point h, where the lines $a\ f$ and $g\ m$ intersect each other, and thus we have two rectangular forces p and P in a state of equilibrium, at the ends of a straight line $h\ g$ revolving round m.

FIG. 22.



The two forces are unequal, as their respective points of application at h and g are at unequal distances from the fulcrum m. We have now to ascertain the relation which exists between the magnitude of the forces p

and P, and the lengths $h\ m$ and $g\ m$. The triangles $c\ a\ f$, Fig. 21, and $a\ h\ m$ are similar to each other, and hence $a\ c : a\ f = h\ m : a\ m$. But the lengths $a\ c$ and $a\ f$ are to each other as the forces p and P; thus we have

$$p : P = h\ m : am,$$

and since $a\ m = g\ m$,

$$p : P = h\ m : g\ m,$$

or

$$p : P = L : l \quad . \quad . \quad . \quad . \quad (1),$$

if we make the length $h\ m = L$ and $g\ m = l$. Or, to express the same fact inwards, we may say that the forces P and p bear an inverse ratio to the distances of their points of application from the fulcrum m.

A straight, inflexible rod turning round a fixed point is called a lever. If two opposite forces at right angles to its direction be applied at two different points of a lever, a state of equilibrium will be established when the above condition has been fulfilled. The distance of the point of application of a force from the fulcrum is called the arm of the lever; and we may, therefore, thus express the condition of equilibrium in the lever. Two forces tending to draw the lever in opposite directions are in equilibrium when they bear an inverse proportion to the corresponding arms of the lever.

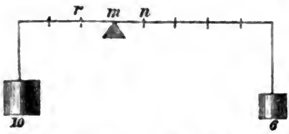
If, for instance, the arm $h\ m$ (Fig. 22) was half the length of $g\ m$, then P must be twice as large as p. A force p may be in equilibrium with a hundredfold larger force P if the arm $m\ g$ be 100 times as long as the arm $h\ m$.

From the proportion (1), it follows that $P\ L = p\ l$, that is to say, in order that two forces in a lever shall be in equilibrium, it is necessary that the products of the force and the distance at which it acts from the fulcrum be equal for both forces. If, for instance, the force $p = 6$ ounces, and the arm be 12 inches, it would be necessary, in order to bring them to a state of equilibrium, to have on the other side an arm three times shorter, that is, 4 inches, acted on by a force three times greater, that is, $3 \times 6 = 18$; it is evident that the product 6×12 is equal to the product 4×18.

The product obtained by multiplying the force by the arm of the lever is called the *static moment* of the force. We may also define the static moment of a force as that force which, acting at an arm of one unit on the opposite side of the fulcrum, shall preserve the state of equilibrium.

In Fig. 23, if we assume that the force to the right = 6, and

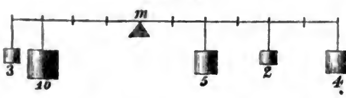
FIG. 23.



the arm of the lever = 5, the static moment of the force will be $5 \times 6 = 30$; then, if the force on the left hand is to be in a state of equilibrium with the former, the static moment of the two must be equal, and the force acting on the left side on an arm equal to 3 must have a valve of 10. But, instead of letting the force 6 act on the arm of length 5, we might, without disturbing the equilibrium, apply a force of 30 on the arm of length 1; and, in like manner, the force 10 acting on the other side of the lever, which equals 3, may be replaced by a force of 30 acting at an arm equal to 1.

When several forces act on each side of the fulcrum a state of equilibrium will be established, if the sums of the static moments on each side be equal. For example, in Fig. 24 *m* is the fulcrum,

FIG. 24.



and on one side the force 5 acts on the arm 2, the force 2 on the arm 4, and the force 4 on the arm 6, while on the other side the forces 10 and 3 act on the arm 3 and 4. Now, all these forces will be in a state of equilibrium, for the sums of the static moments of both sides are equal. The sum of the static moments on the one side is $5 \times 2 + 2 \times 4 + 4 \times 6 = 42$, and the sum of the same forces on the other side is $10 \times 3 + 3 \times 4 = 42$. Instead of the force 5, which acts at the distance 2, we might have the force 10 at the distance 1; thus also the forces 2 and 4, acting at the distances 4 and 6, may be replaced by two other forces, 8 and 24, acting at right angles to arm 1. We may likewise substitute the forces 10, 8, and 24, acting at the distance 1, for the forces 5, 2, and 4, acting at the distances 2, 4, and 6 respectively; or, in other words, we may replace the three forces 5, 2, and 4, acting on their different arms, by one single force of 42, acting at the distance 1. On the other side we may also substitute two forces, 30 and 12, acting at an arm 1, for the forces 10 and 3, acting at the distances 3 and 4; or we may make use of a single force of 42, acting at a distance 1. As the sums of the static moments are equal on both sides, a state of equilibrium must be maintained.

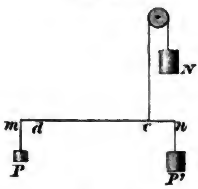
The common steelyard furnishes us with a good example of the

application of the lever, and Fig. 25 may serve to elucidate the principles of this machine. A lever is moveable about the point a, while a scale is suspended at r, to receive the weight acting upon the arm $a\ r$, and this weight is kept in equilibrium by a sliding weight at the other arm of the lever. The heavier the weight is, the further must the sliding weight be removed from the fulcrum r.

FIG. 25.

In such a lever as we have been considering, the fulcrum has to sustain a resistance equal to the sum of the forces on both sides; it may also be in equilibrium when the fulcrum is not fixed, but is moved by a power acting in a contrary direction, but equal to the sum of the other forces. Fig. 26 explains this. Let us assume that c is the fixed fulcrum of a lever $m\ n$, at the ends of which the forces P and P' balance each other. Their equilibrium will not be disturbed by the fulcrum c ceasing to be fixed, if a force n be attached to it, which shall be equal to the sum of P and p, and act in an upward, as the forces P and P' draw in a downward direction.

FIG. 26.



We may regain either of the three points m, c, or n, as fixed without disturbing the equilibrium. If one of the extreme points, n for instance, be fixed, we have a one-armed lever; that is, one in which the two forces N and P act on the same side of the fulcrum n. The two forces have in this case opposite directions, and the pressure upon the point of support is equal to the difference of the two forces P and N. The arm of the force P is $l+l'$, if we designate the length $m\ c$ as l, and the length $n\ c$ as l'; the arm of force N is l'. If c had been the fixed fulcrum we should have had as a requisite condition of equilibrium :—

$$P' : P = l : l',$$

and, consequently,

$$P' + P : P = l + l' : l',$$

or,

$$N : P = l + l' : l'.$$

If, therefore, the forces N and P acting in opposite directions are to be in equilibrium, they must be inversely proportionate to the length of the arms at which they act.

FIG. 27.

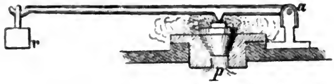
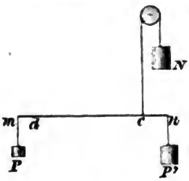


Fig. 27 shows the application of a single-armed lever. The valve p which closes the opening of a boiler is forced up by the pressure of the steam, but this pressure is equipoised by a much smaller force, the weight n acting downwards, because r acts at a longer arm than the pressure on the under surface of the valve.

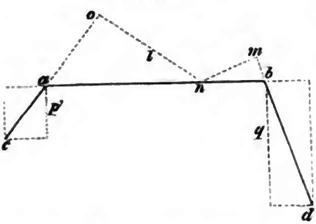
FIG. 28.



The two extreme points (Fig. 28) m and n of the rod $m\ n$ may be fixed, while a force N acts at e; so that the point m has a pressure p, and the point n a pressure p' to support. When two men carry a load hanging to a rod, each one supporting an end of the rod on their shoulders, they have between them the whole weight to carry; and when it hangs exactly in the middle of the pole, it will be equally divided between them; but if the load should be hung nearer to one of them, he will have the most weight to support. Supposing that the appended load weigh 100 lbs., the pole be 5 feet long, and that the load hang 2 feet from one, and 3 feet from the other end, then the shoulders of one bearer will have to support a pressure of 60 lbs., and those of the other a pressure of 40 lbs.

We have hitherto only considered the forces acting at right angles to the lever; equilibrium may, however, be established without this being the case.

FIG. 29.



In Fig. 29 n is the fixed point of the lever $a\ b$; at a the force p acts in the direction $a\ c$, and at b the force q in the direction $b\ d$, the forces p and q bearing the same relations to each other as the lines $a\ c$ and $b\ d$. According to the law of the parallelogram of forces, p may be decomposed into two forces, of which the one p' acts at right angles to $a\ b$, while the other acts in the direction of $a\ b$. In the same way q may be decomposed into two forces, of which one q' act at right angles to $a\ b$, and the other in the direction of that line.

The action of the two component forces which act in the direc-

tion of the line $a\ b$ is evidently fully counteracted by the resistance of the fixed point n, thus leaving only the action of the forces p' and q'. We may, therefore, substitute the component forces p' and q' acting at right angles to the lever in place of the original forces p and q. A state of equilibrium will be established if p' and q' correspond in an inverse ratio to the length of their arms—that is, if

$$p' : q' = n\ b,\ n\ a$$

or if

$$q' \times n\ b = p' \times n\ a.$$

If we prolong the direction of the force p, and draw $n\ o\ (= l)$ perpendicular to it, we have the triangle $a\ o\ n$, which is similar to the triangle whose hypothenuse is p, and one of whose sides is p'; and from this it follows that

$$p : p' = a\ n : l$$

and consequently that

$$p \times l = p' \times a\ n.$$

The force p, acting obliquely on the arm $a\ n$, acts exactly the same as the component force p' acting at the same point a; and also as if the force p acted at right angles to a shortened arm, which is found by letting fall a perpendicular from the fulcrum n upon the direction of the force.

The moment of an oblique force is found by multiplying the force by the perpendicular let fall upon the direction of the force from the axis.

Thus the oblique force q acts as if it met the arm of the lever $n\ m$ at right angles, and the two forces p and q are in equilibrium when $p \times o\ n = q \times n\ m$.

FIG. 30.

By the same process, we find the moment of the forces when the lever does not form a straight line. When any fixed system turns round a fixed axis, the forces that tend to turn it round the axis follow the laws of the lever; and these we therefore find applied in many machines, which may, therefore, be divided into more or less complicated systems of levers. In the windlass and capstan (Figs. 31 and 32) the weight r corresponds to the counteracting force p in an inverse ratio to the arms of the lever; that is, inversely to the radii $a\ b$ and $c\ d$. If, for example, the radius $a\ b$ of the axle is four times less than the radius $c\ d$ of the wheel, we may equipoise a weight of 100 lbs. by a force of 25 lbs.

FIG. 31.

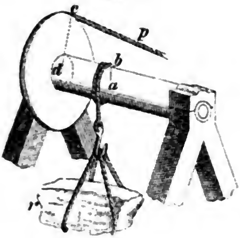
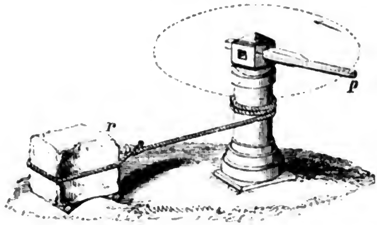


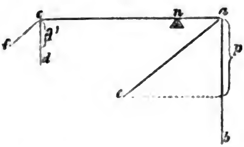
FIG. 32.



The capstan (Fig. 32) only differs from the windlass by having its revolving axis placed vertically, and thus a comparatively small force is required at p to move the weight r.

When two parallel forces acting at right angles to a lever are equipoised, the equilibrium will not be disturbed if we increase or diminish them in equal proportions, or if we keep the forces parallel to each other in altering their direction. If, for instance, the forces $a\ b = p$ and $c\ d = q$, acting on the lever $a\ c$, are equipoised, the equilibrium will not be disturbed if we let the forces act in the parallel directions $a\ e$ and $c\ f$, for the oblique force p acts in the same manner as its rectangular component p', and the oblique force q as the rectangular force q'; and $p'\ q'$ will certainly maintain a condition of equilibrium if it exists between the forces p and q, acting perpendicularly to the lever.

FIG. 33.



Centre of Gravity.—A heavy body, whatever be its size, may be regarded as a combination of innumerable material points, acted upon by gravity. All these forces, although innumerable, may be replaced by one single force acting at a fixed point. This single force, which is nothing more than the sum or the results of all the individual actions of gravity, is termed the weight of a body, and the point at which the resultant acts the *centre of gravity*.

This definition is sufficient to prevent weight and gravity from being confounded. Gravity is the elementary force which acts directly upon all the particles of matter, while the weight of a body is the sum of the actions which gravity exercises upon this body.

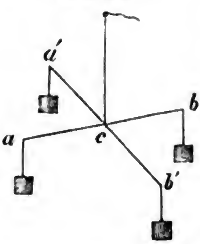
It is very important to be able to ascertain the weight of bodies and their centre of gravity, since we can then substitute one single force, namely, the weight, for all the elementary forces acting on

the body; and one single point, namely, the centre of gravity, for the collective points forming the body. We may thus consider a heavy mass, whatever be its size and form, as a single point, on which one single force acts.

In a heavy body, possessing an extension of even some hundred metres, the direction of gravitation will be not only perfectly parallel for all the molecules, but also perfectly equal for all, because all the molecules will fall with equal velocity *in vacuo*. *The centre of gravity* is consequently nothing more than the centre of parallel and equal forces, where the position does not change when the position of the body with respect to the direction of quantity changes.

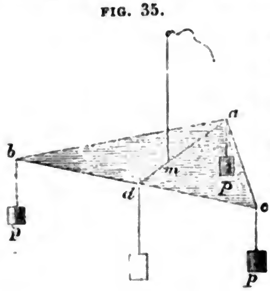
We deduce from the laws of the action of parallel forces the fact that every solid body must have such a centre of gravity. If an immovable straight line *a b* (Fig. 34) be supported at its centre and loaded at both ends with equal weights, the whole will be in equilibrium, in whatever direction the line be turned round the point at which the central force acts, whether the line be in the position *a b*, or in the position *a b′*. Let us assume that the two points *a* and *b* are two heavy molecules, connected by the straight rigid rod *a b*, supposed devoid of weight; then it is clear that equilibrium must occur if only the point *c* be supported, whatever be the position of the line *a b*. The point *c* would be nothing more than the centre of gravity of the body consisting of the two molecules. We may regard the actions of the forces of gravity of the two molecules combined at the centre of gravity, without on that account the equilibrium being disturbed.

FIG. 34.



If at the three angles of a rigid triangle, *a b c* (Fig. 35), supposed to be devoid of weight, three equal and parallel forces are at work, it is easy to ascertain the position of their central force. We may unite the two forces acting at *b* and *e* in the centre *d* of the line *b e* without disturbing the equilibrium, and thus the action of the three forces is reduced to the action of the two acting at the points *a* and *d*. The

FIG. 35.



force acting at *d* is twice as great as that at *a*; if, therefore, we divide the line *a d*, passing through the point *m*, into two parts, of which the one *a m* is twice as long as the remaining part *d m*, a state of equilibrium will necessarily be established between the parallel forces 2 *p* and *p*, acting at *d* and *a*, if only the point *m* be supported, whatever be the position of the line *a d*. But as the force acting at *d* is only the resultant of the parallel forces at *b* and *e*, we may take these forces themselves instead of their resultant; and thus it is clear that the three parallel forces acting at *a*, *b*, and *e* must be in equilibrium if the point *m* be supported, or if a force equal to 3 *p*, acting in an opposite direction, be applied at *m*, whatever may be the position of the triangle in other respects.

If we assume that *a*, *b*, and *e* are three heavy molecules, which must necessarily always retain the same relative position towards each other, then the gravity of these molecules will act in the same manner as the weights attached at *a*, *b*, and *e*, and it is evident that the body consisting of the three molecules will be in equilibrium if only its centre of gravity *m* be supported.

Exactly as we can demonstrate that two or three firmly united molecules must have a centre of gravity, we can likewise comprehend that every 4, 5, 6, &c., firmly-united molecules must have such a centre of gravity, and, further, that every solid body must have a fixed point of that nature, whatever be the number of molecules of which it is composed.

The only requirement necessary to the equilibrium of a heavy body is that its centre of gravity should be supported. If, therefore, the centre of gravity of a body be a fixed point, the body will always be in equilibrium, in whatever manner we may turn it. We may prove this by means of a homogeneous disc, made to revolve round a horizontal fixed axis, passing through its centre of gravity. If a body be supported at a point that does not coincide with its centre of gravity, it may still be in equilibrium, although only in two special positions, when the centre of gravity lies vertically above or below the point of support. This experiment is also easily made by means of a disc.

From these considerations we may deduce a method which will enable us to show by experiment how to find the centre of gravity of a body. If we suspend the body at a point *a* (Fig. 36), the direction of the thread supporting it will pass through a part *c* on the margin of the body. The centre of gravity must necessarily

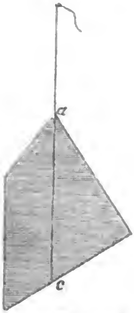


FIG. 36.

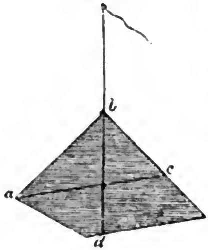


FIG. 37.

be in the line *a c*. Now if we suspend the body at the point *b* (Fig. 37), the centre of gravity will be again in the line of prolongation of the thread, that is, on the line *b d*. The centre of gravity lies, therefore, at the point of intersection of the lines *b d* and *a c*. It is easy to find the centre of gravity of homogeneous flat discs by this method, but it is difficult in other bodies to ascertain exactly the line of prolongation of the thread through the interior of the body.

The centre of gravity of homogeneous bodies of regular form can be decided by simple geometrical considerations.

The centre of gravity of a *straight line* lies evidently in the middle of its length.

The centre of gravity of a *homogeneous triangle* (Fig. 38) is found by drawing straight lines from two of its angles to bisect the opposite sides. The point of intersection *g* of these two lines is the required centre of gravity. The truth of this assertion is easily proved. The point *m* is the centre of gravity of the straight line *b c*. If now we suppose any straight line drawn parallel with *b c* in the triangle, it will evidently be bisected by the line *a m*; on the line *a m* lie, therefore, the centres of gravity of all the lines in the triangle parallel with *b c*; and *a m* is, so to speak, a line of gravity of the triangle, and the centre of gravity must evidently lie in *a m*. This reasoning shows, however, also that the centre of gravity must lie in the line *a b*.

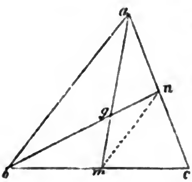
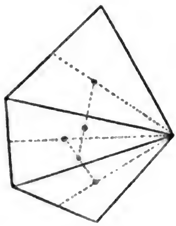


FIG. 38.

The point *g* is so situated that $g\,m = \frac{1}{3}\,a\,m$, and $g\,n = \frac{1}{3}\,b\,n$. To prove this, let the line *m n* be drawn, it is evident that $m\,n = \frac{1}{2}\,b\,a$. But the triangles *g m n* and *g a b* are similar, and hence it follows that $g\,m : g\,a = m\,n : b\,a$. Consequently, that $g\,m = \frac{1}{2}\,a\,g$.

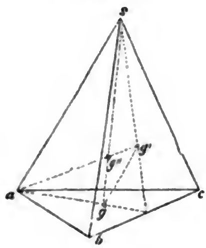
The centre of gravity of a polygon (Fig. 39) is found by

FIG. 39.



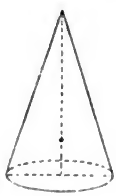
dividing the figure into triangles, and then determining the centre of gravity of each triangle. As the forces acting upon the centres of gravity of the triangles are proportional to the area of the triangles, we have only to seek the resultant of these forces by the rules already laid down.

FIG. 40.



The centre of gravity of a triangular pyramid (Fig. 40) is found by drawing lines from the angle *s* and *a* towards the centres of gravity *g* and *g'* of the opposite triangles. The point of intersection *g''* of these two lines is the centre of gravity. It is easy to prove that $g\,g'' = \frac{1}{4}\,g\,s$.

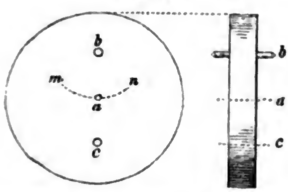
FIG. 41.



The centre of gravity of a cone (Fig. 41) with a circular base lies on the straight line, joining the apex with the central point of the base, and its distance from the central point of the base is $\frac{1}{4}$ of the whole line.

The centre of gravity of a regular prism, cylinder, or sphere, corresponds with the geometrical central point of each.

FIG. 42.



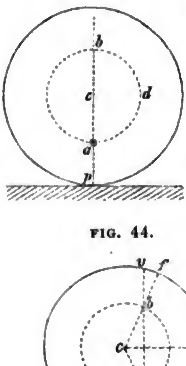
Of Equilibrium.—We have already seen that the only requirement for the equilibrium of a solid body is that its centre of gravity should be supported. But this condition may be fulfilled in various ways, according to whether the bodies are suspended at fixed points, or rest upon points of support. Let us suppose three holes, *a*, *b*, and *c*, in a homogeneous disc (Fig. 42), of which the one, *a*, passes through the centre of gravity. The disc will be in equilibrium in all positions, if a fixed axis is made to pass through the hole *a*. In such a case as this we have an *indifferent* equilibrium. If the axis passes through the upper hole,

b, the equilibrium is *stable*, for if we remove the disc from this position it will always tend to return to it. If we turn the disc a little round the axis *b*, the centre of gravity is moved to the right or left along the arc *m n*; it is no longer supported, because it no longer lies vertically below *b*, and the gravity acting upon it draws it back to its position of equilibrium. If the axis passes through the lower hole, *c*, complete equilibrium is not established, but simply *unstable* equilibrium; for as soon as the centre of gravity is in the least removed from the vertical, passing through *c*, instead of returning, it describes a semicircle until it reaches a point vertically placed below the point *c*.

We may thus generally express this result:—A body attached to an axis may be in a state of stable, unstable, or indifferent equilibrium, according to whether its centre of gravity lies below, or above, or within the axis.

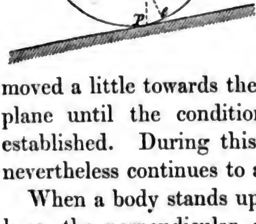
Let us see what happens when a disc is placed upon a horizontal or inclined plane, and assume that the disc is so composed of lead and wood that its centre of gravity lies in the circle *a b d*. In this case none but a stable or unstable equilibrium can exist; the former when the centre of gravity rests at *a*, the lowest point in the circumference *a b d*, and the latter when the centre of gravity is at the highest point, *b*, of this circle.

FIG. 43.



If the same disc were placed on an inclined plane (Fig. 44), equilibrium would be established if the centre of gravity lay in the vertical plane *p b*, passing through the point of contact. Stable equilibrium will then be established when the centre of gravity is at the lowest point *a*, and unstable equilibrium when it lies at the highest point *b*.

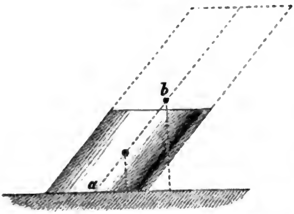
FIG. 44.



If we assume that the disc is in a state of unstable equilibrium, and were moved a little towards the right side, it would roll up the inclined plane until the condition of stable equilibrium was again re-established. During this apparent elevation the centre of gravity nevertheless continues to approach the lowest points.

When a body stands upon the ground, with a more or less wide base, the perpendicular drawn through its centre of gravity must

FIG. 45.



fall within the base, if a state of equilibrium is to be established.

Thus the inclined cylinder would be in equilibrium (Fig. 45), if its height did not exceed the shaded part of the figure; but it must fall if its height were such that the centre of gravity lay at *b*.

The broader its base is, and the lower its centre of gravity lies, the firmer will a body stand. A four-footed animal stands firmly when the centre of gravity of his whole body lies over the parallelogram of which the four angles are indicated by the position of its four feet. If a man raise an arm, the position of the centre of gravity will be changed; and if a bird project its neck, the centre of gravity is thrown considerably forward. A man carrying a weight must change his position according to the manner in which he carries it. For instance, if he bears the load upon his back (Fig. 46), he must bend forward; if he carry it in his left hand (Fig. 47), he must incline the upper part of his body to the right,

FIG. 46.

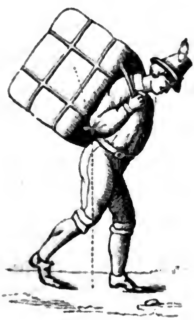


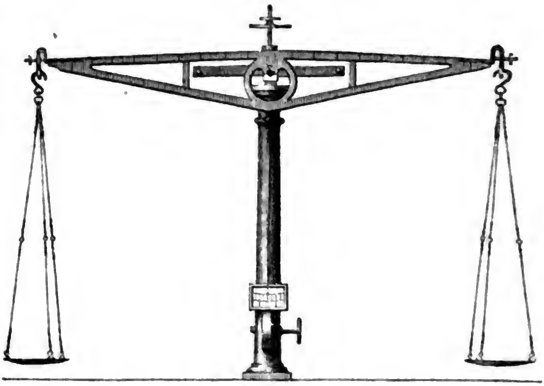
FIG. 47.

otherwise the direction of the common centre of gravity of the human body and the load would fall beyond the line connecting the feet, and the man would fall.

The Balance.—The common balance consists essentially of a rod called a beam, which revolves round a fixed horizontal axis inserted in its centre. When there is no load at either end, the beam should be in a perfectly horizontal position. To either end of the

beam scale-pans are suspended, which serve for the reception of the bodies to be weighed. If both pans are equally loaded, the beam

FIG. 48.



will retain its horizontal position; but, if an unit of weight is laid upon one of the pans, the beam will incline towards that side.

We will now inquire how the conditions above mentioned can be satisfied. If we first suppose that the scale-pans are removed, and assume that the horizontal axis passes through the centre of gravity of the beam, we shall have a case of *indifferent* equilibrium, and the beam will be in equilibrium at any angle with the horizon. Such an arrangement will not, therefore, fulfil the first condition, namely, that the beam should assume a horizontal position before the pans are loaded. This condition can only be fulfilled if the centre of gravity of the beam lie below the fulcrum.

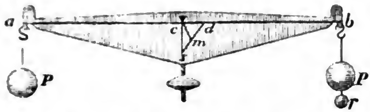
If we draw a line at right angles with, and bisecting the longer axis of the beam, this line must pass through the fulcrum of the beam, and through its centre of gravity.

The suspension of the pans makes no difference in our reasoning, for we may consider their weight concentrated at the point of suspension, and that they thus form an integral part of the beam.

If we unite the points of suspension of the pans by a straight line, this line may pass through the fulcrum, or above or below it. It is most easy to take into consideration the first of these three

cases, while it is likewise the most available for practical application; we will, therefore, begin with this case.

FIG. 49.



In Fig. 49 let *a b* be the straight line uniting the points of suspension of the pans, whose weight we regard as concentrated at the points *a* and *b*, and let *c* be the point at which the beam is suspended, that is to say, the point of support; and *s* the centre of gravity of the beam. If equal weights *P* are suspended at *a* and *b*, the beam will remain in a horizontal position; for we may consider that one of the weights acts directly upon *a*, and the other directly upon *b*, and thus the common centre of gravity of the two weights *P* will correspond with the point *c;* and the common centre of gravity of all the weights suspended at *c*, that is to say, of the beam and of the weights *P*, will meet at a point between *c* and *s;* this common centre of gravity lying vertically under the point of support, the equilibrium is not disturbed.

If we apply an extra weight *r* on one side, the centre of gravity of the suspended weights, which we must necessarily consider as concentrated at the points *a* and *b*, no longer corresponds with *c*, but falls on the line *a b*, in the direction of the extra weight, somewhere towards *d*. The common centre of gravity of the beam and the weights will consequently be upon some point, *m* in the line *d s;* but since, while the beam is horizontal, the common centre of gravity *m* is no longer vertically beneath the point of suspension *c*, the whole beam must revolve sufficiently around the axis *c* to fulfil this condition. Hence the arm *c a* will necessarily rise, and the arm *c b* sink. The angle which, on the addition of a slight excess of weight in either pan, the beam makes with an horizontal line is termed the *angle of deviation.*

We shall now consider the points that must be attended to for the construction of the balance, in order to render it sufficiently sensitive; that is to say, in order that a very slight preponderance of weight may give rise to a large angle of deviation.

1. *The centre of gravity of the beam must lie as closely as possible below the centre of suspension;* for if, in case (the other conditions remaining unaltered) the centre of gravity *s* of the beam is raised upwards, then the point *m* will also be elevated vertically, which must evidently produce an increase in the angular deviation of the beam. A contrivance has been applied to good balances by which

the position of the centre of gravity is regulated. A fine screw is applied to the prolongation of the line *c s*, on which a weight corresponding to circumstances may be screwed up and down, by which a change in the position of the centre of gravity is manifestly effected.

If this weight were screwed up so far that *s* corresponded with *c*, we should have either without a load, or with an equal load on both sides, a case of indifferent equilibrium; were we now to bring an extra weight *r* on one side, the point *m* would fall upon the line *a b* (see Fig. 49); that is to say, on the addition of the smallest extra weight the angle of deviation would become a right angle, the beam would be completely inverted, and, in short, the instrument would cease to be of any service.

2. *The sensibility of the balance increases with the length of the beam.* If (everything else remaining the same) we were to lengthen the beam, the distance *c d* would be proportionally greater, and the point *m* would thus also be removed further from the line *c s* in a direction parallel to *a b*, and consequently the line *c m* would make a larger angle with *c s*, and the angle of deviation would also increase. (It is easy to see that the angle *m c s* is equal to the angle of deviation.)

3. *The beam must be as light as possible.* We may suppose the weight of the loads $2\ P+r$ acting at the point *d*, and the weight of the beam, which we shall designate as *g*, united at *s*. The position of the common centre of gravity *m* will now evidently depend upon the amount of the forces acting at the ends of the line *d s*. If the weight *g* at *s* and $2\ P+r$ at *d* be equal, *m* would fall in the middle of *d s*; but the smaller *g* becomes in comparison with $2\ P+r$, the more must *m* recede from *d*, and the larger proportionably will the angle of deviation be. In relation to the two last points, we are confined to certain limits which we cannot exceed, since too great a length of the beam would render the balance inconvenient for practical purposes, and too great a degree of lightness would deprive it of the necessary strength.

As a matter of course, the greatest care must be had in the construction of the balance to render the two portions of the beam of equal length. As, however, slight errors cannot be avoided, we must endeavour to correct them by means of the method of weighing which is had recourse to. The best manner of proceeding in this respect is probably the following:—The body to be

weighed is laid upon one scale-pan, and equipoised by a sufficient quantity of sand, shot, or any other substance laid in the opposite scale-pan. This done, the body to be weighed is then removed, and in its place so many weights are substituted as to restore the balance to equilibrium. These newly-applied weights will give the accurate weight of the body, whether or not the arms of the beam be equally long.

The fulcrum is formed of a steel knife-edge, in order as much as possible to avoid friction, and the scale-pans are suspended from similar edges.

CHAPTER II.

MOLECULAR EQUILIBRIUM.

We have already seen that, in order to explain the aggregate conditions of bodies, we assume the existence of molecular forces, which act continuously among the separate particles of bodies. As long as a body remains unchanged in its internal condition, and as long as the individual particles remain not only at unchanged distances, but also in a relatively unchanged position, the molecular forces acting among the individual particles must remain in equilibrium. The equilibrium established between the separate particles of solid bodies is *stable*, for a greater or lesser force is necessary to disturb this condition.

As we have already seen, the force of cohesion preponderates in solid bodies, holding their particles together, and acting alike against their displacement and separation; it being necessary to employ a greater or lesser force to bring about any such displacement or separation.

Elasticity.—When the particles of a solid body have been slightly drawn out of their relative position by an external force, the previously existing state of equilibrium is not on that account entirely destroyed, for the particles may return to their former position when the disturbing force ceases to act. This property of bodies, by means of which the molecules return to their former position when the displacement occasioned by an external force does not exceed certain limits, we term *elasticity*. The elasticity of solid bodies proves that the molecules are in a state of stable equilibrium, since it is only under such circumstances that a body returns to its position of rest, when the external disturbing force has ceased to act. All bodies are not equally elastic: there are some which perfectly assume their former position after even a very considerable amount of displacement, and such bodies are especially termed elastic, as, for instance, india-rubber, steel, and ivory;

others, on the contrary, as lead, glass, &c., are only elastic to a limited degree, not being able to bear any great displacement of their particles without the previous condition of equilibrium being disturbed.

The displacement of the particles may either be occasioned by tension, compression, or rotation.

When a proportionately large power is necessary to produce a displacement of the particles of a body, we term the latter *hard*. A body may be both hard and elastic, as is the case with ivory and steel; glass, on the contrary, is hard, and but slightly elastic.

A body whose particles can be removed by an inconsiderable force is called *soft*. Soft bodies may be elastic, as india-rubber: or they may possess merely a small degree of elasticity, as is the case with moistened clay. The aggregate condition of such soft bodies may in some measure be considered as an intermediate state between perfect solidity and perfect fluidity.

If the particles of a body are displaced beyond the limits of elasticity, the connection hitherto existing between them either ceases entirely, or the molecules arrange themselves in a new condition of stable equilibrium. In the first case we call the bodies *brittle*, in the next *ductile*. The external form of brittle bodies cannot be permanently changed by pressure, blows, &c.; a perfect separation following when, by means of such external causes, the molecules are displaced beyond certain limits; the form of ductile bodies can, however, be permanently changed by such mechanical means as we see, for instance, in the stamping of coins.

Strength.—The force with which a body resists the separation of its particles is termed its *strength*.

The connection existing between the individual portions of a solid body may be removed by tearing, breaking, twisting, or compressing it.

Absolute Strength is the force by which a body resists being torn asunder when it is stretched lengthways. This resistance evidently depends upon the diagonal section of the body to be severed, and is proportional to it, for the connection of two, three, four times as many molecules must be removed if the diagonal section or area of a body be increased twice, thrice, or four times. In order, therefore, easily to compare the absolute strength of different materials, we must assume some unit for this area, and then ascertain how great a force is required to rend a body, the area of

which is equal to this unit. If the area of the body submitted to the experiment be greater or smaller than the area assumed as the unit, the strength may be reduced to the measure of that unit.

Muschenbroek has made numerous experiments concerning the absolute strength of different bodies. The following table gives, according to his calculations, the weight required to break a rod of different bodies whose diagonal section is one square centimetre:—

Linden wood	918	kilogrammes.
Fir (Pinus silvestris) . . .	1021	„
White pine (Pinus abies)	601 to 929	„
Oak	1150 to 1466	„
Beech . . .	1349 to 1586	„
Ebony	934	„
Copper wire	2782	„
Brass wire	3550	„
Gold wire	4645	„
Lead wire	272	„
Tin wire	457	„
Silver wire	3411	„
Iron	4182	„
White glass . .	142 to 233	„
Rope . . .	350 to 620	„

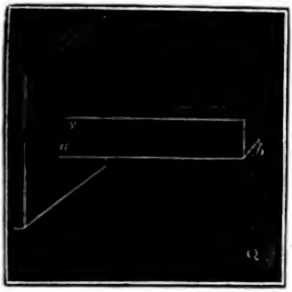
The great variation perceptible in the strength of rope depends upon the unequal character of the material of which it is made. Thin ropes are proportionally stronger than thick ones, from being made of better hemp. Ropes have less firmness when wet than when dry.

It will be most safe to assume for practical purposes that metals possess only $\frac{1}{2}$, and wood $\frac{1}{3}$, of the absolute strength ascribed to them in the above table.

The force which a body opposes to the process of breaking is its relative strength. In order to break a body, the force must be applied at right angles to the directions of its long axis; the body to be broken being supported only at one, or at both, of its extremities.

Fig. 50 represents a prism, which is fastened at one end into a solid wall, while at the other extremity is attached the weight Q to break it. If K represent the absolute strength, that is, the force with which the body resists the force endeavouring to

FIG. 50.



destroy it and acting upon it in its long axis, we may suppose this force concentrated at the centre of gravity s of that diagonal section which corresponds with the plane of the solid wall. The weight Q manifests an effort to turn the whole body round the under edge of the prism; and thus acts at the arm $a\ b$, while the resistance applied at s acts at the arm $a\ s$; if now the resistance shall exactly counterpoise the force, the resistance K must be inversely to the force Q as the arm $a\ s$ is to the arm $a\ b$. If the height of the beam be represented by h, $a\ s = \frac{1}{2}\ h$, and if the length $a\ b$ be represented by l, we have

$$K : Q = l : \tfrac{1}{2}\ h$$

or,

$$Q = \frac{K\,.\,h}{2\ l}.$$

The amount of strength K with which the body resists being rent asunder depends upon the diagonal section of the beam. If we let k represent the absolute strength for one diagonal section of one square centimetre, while h is the height and b the breadth of the beam, then

$$K = k\ b\ h,$$

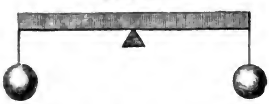
and therefore,

$$Q = \frac{k\ b\ h^2}{2\ l}.$$

From this formula, we see that the force necessary to break the body varies in a direct ratio with the breadth and the square of the height, and inversely with the length.

If a beam be supported in the middle by a sharp edge (Fig. 51,)

FIG. 51.

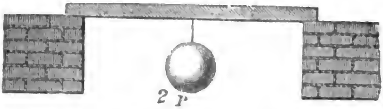


and be loaded at both its extremities with equal weights P, there will exist a tendency to break the beam at its centre; in order to effect this, the weight P acting at each end must be twice as great as the weight Q, which must be applied to the end of the same beam if projected its whole length from a solid wall,

as in Fig. 50, since the weight P acts upon a lever only half the length of that supporting the weight Q.

The pressure which has to be supported in the middle is evidently $2\,P$.

FIG. 52.



If the beam be supported at each end as in Fig. 52, we may break it by attaching a weight $2\,P$ to the middle. As $P = 2\,Q$, we must apply, in order to break a beam supported at each end, a force four times as great as would be necessary to break it if it projected its whole length from a solid wall, and the force acted upon the free end. The force necessary for breaking it is therefore

$$4\,k\,\frac{b\;h^2}{2\;l}.$$

By the length of the beam we understand, in the one case, the part projecting from the wall; and in the other, the portion lying between the two points of support.

We have not taken into consideration in our calculations that the beams bend before they entirely break. By this bending, the relative strength is considerably modified, so that the value of the relative strength computed according to the above formulæ, from the known absolute strength, may vary considerably from the reality. But, if these formulæ do not serve to compute directly the amount of the relative strength, they yet serve for a comparison of the relative strengths of beams and rods, when formed of the same material, but of different dimensions; for, however the amount of the absolute strength may be modified by flexibility, it is always directly proportionate to the breadth and square of the height, and inversely so to the length; therefore, in the formula

$$Q = k\,\frac{b\;h^2}{2\;l}$$

nothing is changed by the flexibility but the value of the constant factor k, which must be replaced, not by the value of the absolute strength taken from the above tables, but by another factor, which must be obtained by experiment for each material. Experiments show that the force necessary to break a beam is four times as small as is given by the above formulæ, if we substitute for k the

number indicating the absolute strength. The influence exercised by flexibility upon the relative strength is also proved from this, that, if a beam rests freely on both its extremities, it may be broken by a weight suspended at its centre, only half the amount of that necessary to break it when it is fixed at both ends, and, consequently, incapable of yielding.

In woods, the direction of the fibres has naturally also much influence upon the strength.

Adhesion.—The same force which holds together the particles of a solid body, acts also in holding together the particles of two bodies already separated, if we are able to bring them within a sufficiently intimate contact with each other. Thus plates of mirrors, which are laid closely one upon another after being polished, often adhere so tightly that they cannot be separated without breaking. In the same manner two plates of lead, when pressed together, will adhere almost as closely as if they formed one single mass, provided always that the surfaces brought in contact are perfectly smooth and metallic.

The force thus connecting two bodies is termed the force of *adhesion.*

Adhesion is manifested not only between homogeneous, but also between heterogeneous, bodies. Thus a plate of lead and a plate of tin, or a plate of copper and a plate of silver, combine to form an almost inseparable whole, when their polished surfaces are compressed by a heavy cylinder. The adhesion of heterogeneous bodies is most strongly manifested when a fluid is brought in contact with a solid body; and the former is solidified by the cooling or evaporation of the dissolving medium, as we see exemplified in the processes of pasting, gluing, and cementing. It often happens on joining together two pieces of glass with sealing wax that on tearing the whole asunder, pieces are separated from the glass, instead of the glass being severed from the wax. If we rub a plate of glass with glue, the two substances often adhere so closely together that portions of the former will be torn away on the contraction of the glue in drying.

If two bodies having smooth surfaces lie one upon the other, any attempt to push the one beyond the other will be opposed by the force of adhesion, which shows that this latter force has a share in the *resistance of friction,* which opposes itself wherever two bodies glide over each other, or where one body rolls over another. We shall subsequently treat more fully of *friction.*

Crystallization.—If a body pass from a fluid or gaseous form to a solid condition, the change is owing to the preponderance of the cohesive force, which fixes the hitherto moving particles in a relatively definite position. In this transition to a solid condition we see a tendency throughout all nature to produce a regular arrangement of the molecules, and the force exercising this tendency in inorganic nature is *crystallization.*

Crystals are such solid bodies as have a regular form limited by plane surfaces. In nature we find a number of these crystals: for instance, quartz, calcareous spar, heavy spar, topaz, garnet, &c., are often found beautifully crystallized.

A body almost always assumes the crystalline form on passing from a fluid to a solid condition. This transition is effected either by the cooling of a melted body, or by separation from a solution.

If we pour melted bismuth into a warmed cup, a solid crust will, after a time, be formed upon the upper surface. If, now, we puncture this crust, and pour off the remaining fluid metal, we obtain large cubic crystals, measuring several lines in length, and filling up the cavity which is formed by the cooled and solid crust.

We may obtain crystals from a melted mass of sulphur in a similar way.

On attentively observing a portion of water in the act of freezing, we see delicate needles of ice forming, and every moment spreading and ramifying. It is true that we seldom see such regular crystalline formations in ice as in snow, but still it is sufficiently evident that the formation of ice is a process of crystallization.

Many bodies dissolve in fluids, as, for instance, in water; but only a definite quantity of any substance will dissolve in a definite quantity of water, although more is generally dissolved in hot than in cold water. If a solution be saturated at a high temperature, that is, if, for instance, as much alum has been put into warm water as the definite quantity of the liquid will dissolve, the whole mass of salt will not remain wholly dissolved on cooling, but a portion will be again deposited, and in the form of regular crystals. Crystals will likewise be formed when the water gradually evaporates from a saturated solution.

Crystals are not separated from aqueous solutions only; sulphur, for instance, dissolves in bisulphuret of carbon, chloride of sulphur, and oil of turpentine; and we may obtain beautiful transparent crystals of sulphur from these solutions.

The slower the cooling or evaporation, the larger and more regular will the crystals be. In rapid crystallization small crystals are formed which unite together in irregular groups, in which we can scarcely recognise the crystalline outline.

Every substance has its own form of crystallization. Thus, for instance, the form of quartz is different from that of alum, and this latter varies again from that of sulphate of copper (blue vitriol).

The investigation into the laws of symmetry which are found to enrol between the separate surfaces of crystals, as well as the description of crystalline forms in particular, are subjects which belong to the province of *Crystallography.*

CHAPTER III.

HYDROSTATICS, OR THE THEORY OF THE EQUILIBRIUM OF LIQUIDS.

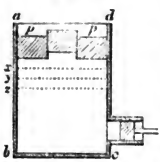
Hydrostatics treat of the conditions of equilibrium in liquid bodies, and of the pressure which they exercise upon the walls of the vessels in which they are contained.

The properties of liquid bodies are dependent upon two forces, namely, on gravity, which acts upon them as upon all other bodies; and on molecular attraction, the action of which is so modified in them as to give rise to their liquid condition. We may easily separate in our minds the actions of these two forces, for we may form a conception of a mass of water devoid of weight, although not ceasing to be fluid.

Such a mass left to itself would not fall; it is evident that to be at rest it neither requires to be supported from below nor to be contained in any vessel. In this condition the fluid might sustain and propagate a pressure according to a law which we will at once consider.

Principle of the equality of pressure.—Fluids have the property of regularly propagating to all parts the pressure exercised upon a portion of their Surface.—This principle is a physical axiom; and, if it be not necessary to prove it, we might at any rate make it intelligible.

FIG. 53.



Let $a\ b\ c\ d$ (Fig. 53) represent a vessel containing a liquid supposed to be devoid of weight; p is a solid plate, completely covering the upper surface of the fluid, which we will also suppose to be devoid of weight. If the fluid is not pressed upon by any weight, it evidently cannot suffer any pressure, and we might bore the vessel at any spot without the fluid escaping. But as soon as we load the plate with a weight, say, for instance, 100 lbs., it will

manifest a tendency to sink, and would sink if the fluid did not hinder it from doing so. The fluid, whether compressible or not, must now support the 100 lbs. The upper surface x will, therefore, support the whole pressure, and would necessarily be pressed down, if it were not kept up by the layer y. The layer x presses accordingly upon the layer y with the same force with which it is pressed by the plate. Thus the layer y presses upon the next one z, and in the same manner the pressure is conveyed to the bottom, which is itself pressed upon, as if the plate rested immediately upon it. As now the whole bottom sustains a pressure of one hundred pounds, it is evident that the half of the surface of the bottom will bear only a weight of fifty pounds, and the hundredth part of the same surface only one pound. Hence it follows:—

1. That the pressure is communicated from above downward to horizontal surfaces without diminution.
2. That it is equal at all points.
3. That it is proportionate to the extension of the surfaces considered.

The same occurs with regard to the lateral surfaces. If we were to make an opening in the lateral wall, the water would gush forth; and if we were to cut out of the wall a piece, the surface of which should equal that of the plate, we must have a counter pressure of one hundred pounds. If the plate itself had an opening, the water would gush forth from it, by which it is evident that the under surface of the plate is pressed upon, exactly the same as all the other portions of the walls. Fluids, therefore, communicate a pressure, exercised upon any part of their upper surface, equally in all directions. If we once understand this principle with regard to fluids devoid of weight, it can easily be applied to heavy fluids on each molecule of which a pressure is exercised, arising from their own proper gravity.

The Hydraulic Press depends upon the uniform communication of pressure by fluids, and consists of two main parts, a sucking and forcing pump, which exercise the pressure, and a piston with a plate to receive the pressure, and convey it to the bodies to be pressed.

Fig. 54 is a section, and Fig. 55 a complete representation on a small scale of the hydraulic press. The piston s is raised by the levers l, and the water of the reservoir b pressing through the perforated vessel r lifts the valve i, and thus gets beneath the piston s. If we press down the lever l, the piston s goes down, the water is

forced back, closes the valve *i*, raises the valve *d*, and runs through the tube *t b u* into the cylinder *c c′* of the press: here it presses

FIG. 54.

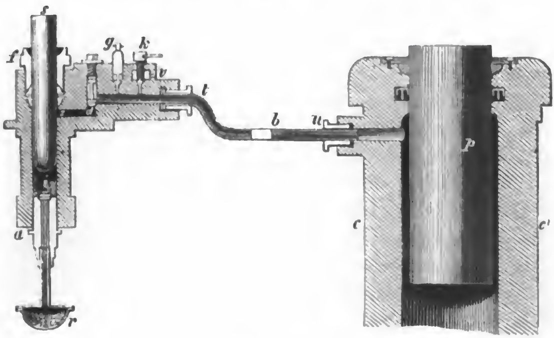
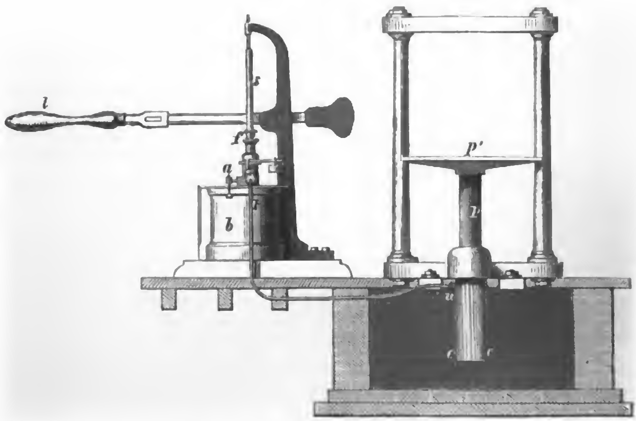


FIG. 55.



against the piston *p*, which it lifts with the plate *p*, and thus the body to be acted on is compressed between *p′* and the fixed plate *e*.

The efficiency of the hydraulic press rests upon the principle that fluids communicate every pressure equally in all directions. If the piston *s* be pressed down by any force, each portion of the surface of the walls of the vessel, which is equal to the diagonal

section of the piston, has to sustain an equal pressure. But now we may regard the under surface of the piston p as a part of the wall of the vessel; therefore, as many times as the diagonal section of the piston p is greater than the diagonal section of the piston s, so many times will the force with which the piston p is elevated be greater than the force with which the small piston is depressed.

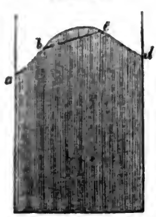
If the area of a section of the piston s is $\frac{1}{100}$th of the area of the piston p, then p will be elevated with a force of 100 pounds, if s is pressed by a force of one pound. But with the help of the lever l, a man may easily exercise a pressure of 300 pounds on the piston s, and therefore raise the piston p with a force of 30,000 pounds.

A portion of the force applied to the lever l is lost by the resistance of friction before it is transmitted to the piston p: the effect, therefore, will always be less than what it should be according to the above considerations.

Equilibrium of heavy Fluids.—Two conditions must be fulfilled in order that liquid bodies should be in equilibrium. First, their free surfaces must be at right angles with the direction of gravity; and secondly, the forces of pressure acting on each particle must always be equal and opposed, the one to the other.

If we assume that the upper surface of the fluid is not at right angles with the direction of gravity, but takes such a form as a b e d (Fig. 56), we may suppose an inclined plane laid through any two points, b and e; a portion of the fluid lies on this inclined plane, and must necessarily glide off from the easy displacement of the particles. This will continue until the whole upper surface is every where at right angles with the direction of gravity.

FIG. 56.



If we apply this to the upper surface of the sea, which we will consider as perfectly at rest, it is clear that if the force of gravity alone acts, and is always directed towards the central point of the earth, the superficies of all seas must be portions of a spherical surface, and that, therefore, the surfaces of seas connected together must be equally remote from this central point.

If the molecules are attracted by other forces than terrestrial gravity, we may easily understand that their free surfaces must be at right angles to the resultant of gravity, and all the other simultaneously acting forces. As the centrifugal force, which depends on the rotatory movement of the earth, continually acts with

gravity upon all bodies, the upper surface of the waters must assume such a position as to be at right angles with the resultant of both forces. This is also the reason that the sea is flattened at the poles. At the foot of great mountains which cause the plummet to diverge, the surface of the water also deviates from the regular form. In the same way the attractive force of the moon, which acts upon the water, combines with gravity to create a resultant which is not vertical. The moving surface of the sea always strives to attain to a position of equilibrium, which is constantly disturbed by the motion of the moon, and hence the periodical oscillations of ebb and flow.

We also observe deviations from the normal surface in fluids enclosed in vessels: thus water in a glass is not even over its whole surface, but rises around the margin; the surface of mercury, on the contrary, is depressed at the sides, as if it dreaded coming in contact with the walls of the vessel. These phenomena depend upon the laws of capillary attraction, which we purpose, subsequently, to consider more fully.

The second condition of equilibrium is self-evident, for the molecules that are in the interior of the fluid sustain a pressure from all the other molecules lying over them, which they transmit in all directions. But if the various pressures, acting in different directions upon one molecule, were not equal, it would be displaced by the strongest pressure, and consequently the fluid mass would not be in equilibrium.

Pressure of Fluids.—If fluid masses are in a state of equilibrium, they exercise upon themselves and on all solid bodies which they touch, a more or less considerable pressure, the amount of which we will now determine. In the first place we will examine the pressure exercised from above downwards, or from below upwards, on horizontal surfaces, and then the pressure acting upon the lateral surfaces.

The pressure exercised by a fluid from above downward on the bottom of the vessel in which it is contained is quite independent of the form of the vessel, and is always equal to the weight of a column of the fluid, whose base is the bottom of the vessel, and whose height is the vertical distance from the bottom to the surface of the fluid.

The first part of this assertion is easily proved by help of the following apparatus:—The apparatus (Fig. 57) consists of a bent tube, *a b c* fastened in a box, and so arranged that vessels of

different form, as those at *d e f g* (Figs. 58, 59, and 60), may be screwed on at *a*. We pour mercury into the tube, and with the

FIG. 57.

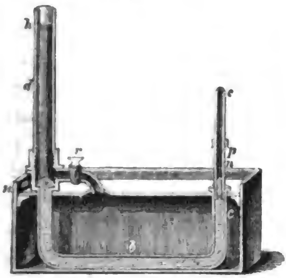


FIG. 58.

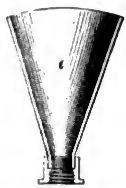
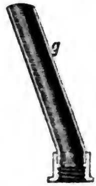


FIG. 59.

FIG. 60.



help of a moving index indicate the height *n* to which the mercury rises in the arm *c*. If now the cylindrical vessel *d* be screwed on at *a*, and filled with water to a definite height *h*, the mercury will rise in the tube *c* to a height *p*, which we must mark. The rising of the mercury *n p* evidently depends upon the pressure exercised by the water in the vessel *d* upon the surface of mercury which forms the true bottom of the vessel. When this has been duly observed, we empty the vessel *d* by the help of the cock *r*, and screw on in its place either the vessel *e*, widened at its upper margin, or *f*, tapering off towards the top. If we fill these vessels with water, as high as we before did the vessel *d*, the mercury in the tube *c* will again rise exactly to the height *p*. The pressure, therefore, which the bottom of these three differently shaped vessels bears is precisely the same, if only the height of the fluid be the same. The pressure on the bottom is, therefore, as we before observed, independent of the form of the vessel, and only depends upon the size of the bottom, the height and nature of the fluid. The pressure is the same, whether the vessel be cylindrical, contain much (Fig. 61) or little (Fig. 62) fluid, be rectangular (Fig. 63) or inclined (Fig. 64). In order to prove the second part of the

FIG. 61.

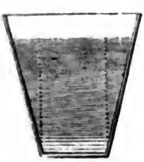


FIG. 62.

FIG. 63.

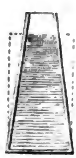
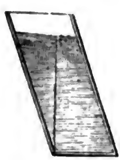


FIG. 64.



proposition, it will suffice to remark, that the bottom of the cylindrical vessel (Fig. 62) must bear the whole weight of the fluid, for, as the lateral walls are vertical, they are incapable of supporting the least part of the weight of the fluid. As, now, the bottoms of the inclined vessels, whether they are widened or contracted at their upper margin, sustain the same weight, it follows that in these vessels the pressure is no longer equal to the weight of the fluid they contain, but is equal to the weight of a straight column of water having the same surface and height. As all parts of the bottom are pressed upon with equal force, it is clear that the half, the third, fourth part, &c., must sustain $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$ of the whole pressure. If we designate by g the portion of the bottom, we are considering by h the height of the smooth surface, and by d the density of the fluid; the pressure upon the surface s is equal to $s \times h \times d$, for $s \times h$ is the volume of the straight column of fluid, and in order to obtain the weight we must multiply the volume by the density.

With a litre* of water weighing a kilogramme,† we may therefore exercise a very small, or any unlimitably large amount of pressure upon the bottom of a vessel. If the pressure upon the bottom is to be exactly one kilogramme, we must take a straight cylindrical vessel of any base we choose, when the combined pressure upon the whole surface will always be one kilogramme; only the pressure which each square centimetre of the bottom has to sustain will be large or smaller, as the vessel is wider or narrower.

If we would exercise upon the bottom of the vessel a pressure of $\frac{1}{10}$ of a kilogramme with one kilogramme of water, we might take, for instance, a vessel whose bottom should measure a square decimetre, and which was so widened towards the top, that a litre of water would only fill it to the height of one centimetre.

If the pressure was to amount to ten kilogrammes, we might take a vessel of the same base (one square decimetre) so narrowed towards the top, that a litre of water would rise in it to the height of ten decimetres.

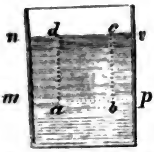
With a similar weight of one kilogramme of water, we might

* The litre is equal to 1.760 pints, or nearly equivalent to the English quart.

† The kilogramme is equal to 15,433 grains, or rather more than two pounds avoirdupois.

with equal ease exercise a pressure of $\frac{1}{100}$, $\frac{1}{1000}$ &c. part of a kilogramme, as one of 100, 1000, &c. kilogrammes. The pressure of fluids acts not only on the bottom of the vessel, but upon every point in the interior of the fluid mass. If we assume in the interior

FIG. 65.



of a fluid mass a stratum *m p* parallel with the surface, all the molecules of this stratum will evidently be pressed upon by the fluid over it, bearing the weight of the fluid cylinder *n v m p*. The stratum must, however, sustain an equal pressure in an opposite direction from below upwards. If now we consider a part *a b* of the said stratum, we find that the weight of the fluid column *a b c d* presses upon it from above downward, while an equal force acts from below upwards. If, therefore, we immerse a solid cylinder in the fluid, its base will have to support a pressure from below which strives to raise it.

This may be proved by the following experiment:—Take a

FIG. 66.

somewhat wide glass tube *v* (Fig. 66), whose lower margin has been smoothly polished: *t* is a perfectly smooth glass disc, secured in its centre by a thread passing through the tube, so that by drawing the thread, the disc may be made entirely to close the opening of the tube. When secured in this manner, we immerse the tube in the water. Now, it is no longer necessary to draw the thread in order to prevent the falling of the disc, for it is pressed upwards by the fluid. If we pour water into the tube, the glass disc will fall by its own weight as soon as the level of the water in the tube is almost equal to that of the water in which it is immersed, for now the glass disc sustains equal fluid pressure upwards and downwards.

If, accordingly, we were to make an opening in a ship; the water would instantly enter the vessel, we must, in order to hinder this, exercise a counter pressure equal to the weight of a column of water, the same base as the opening, and of the same height as the depth of the opening below the level of the water. The bottoms of large ships must, therefore, be very strongly built to sustain the pressure of the water from below upwards. If we assume that the bottom is horizontal, and has superficies of 100 square metres, this pressure would amount to 100,000 kilo-

grammes if it were one, and 300,000 kilogrammes if it were three, metres below the level of the sea.

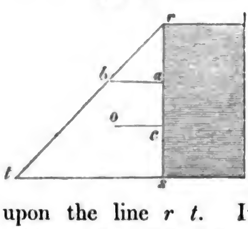
We may thus form an idea of the enormous pressure sustained by the living creatures inhabiting the depths of the seas and oceans. We shall again revert to this subject.

The pressure which a given portion of lateral wall has to support, is equal to the weight of a column of fluid whose height is equal to the depth of the centre of gravity of this lateral wall below the level of the fluid, and whose horizontal base is equal to the size of the given portion of the wall.

The amount of lateral pressure may be obtained from the corresponding horizontal pressure, according to the principle of the uniform transmission of pressure in all directions. The point *m* (Fig. 65) is a point in the horizontal layer *m p*; the pressure to which it is exposed transmits itself uniformly in all directions therefore, also at right angles to the wall. Every point of the lateral wall sustains, therefore, the same pressure as every point of the equally high horizontal stratum of fluid. If, now, we consider any portion of the area of the lateral wall, whose highest point is so little elevated above the lowest point that the pressure sustained by both may, without any great error, be assumed as equal, then we find that the pressure sustained by this portion of the area is $s \times h \times d$, if s, h and d have the previously assumed significations. In a vat full of water, ten metres in height, the pressure upon a square centimetre of the lateral wall at the depth of one metre is equal to 100 grammes; and at two metres to 200 grammes; and at ten metres, that is at the bottom, to one kilogramme.

The pressure sustained by any point of the vertical wall of a vessel filled with water may be made manifest by a diagram (Fig. 67). From *a* let a straight line be drawn *a b*, equal in length to the depth of the point *a* below the level of the water, *a b* will then represent the pressure which the point has to sustain. If we make the same figure for several points of the vertical line *r s*, the extremities of all the horizontal lines of pressure will fall upon the line *r t*. It follows, therefore, that the combined pressure which the line *r s* of the vertical wall of the vessel has to sustain is represented by the triangle *r s t*. The point of applica-

FIG. 67.



tion of the resultant of all the elementary pressures sustained by a section of a wall is called the centre of pressure. It always lies deeper than the centre of gravity of the section, because the pressure increases in intensity downwards. The centre of pressure for the vertical line *r s* is easily obtained, for it is evidently the point *c* at which the line *r s* is intersected by the horizontal line passing through the centre of gravity *o* of the triangle *r s t*. We have here only considered a line *r s*; but, if for this we substitute a broad band of the vertical wall, its centre of pressure will lie upon its vertical central line, and its height above the bottom will be one third of the height of the level of the water above the bottom.

Communicating vessels.—The above developed conditions of equilibrium are valid equally for fluids contained in vessels that are connected together; that is to say, if both vessels contain the same fluid, the level must be the same in both. If we assume a horizontal partition wall to be applied at *m* to the vessel (Fig. 68), we obtain two vessels.

FIG. 68.

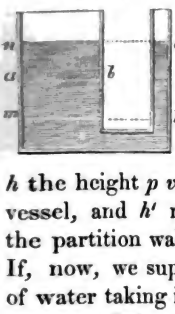
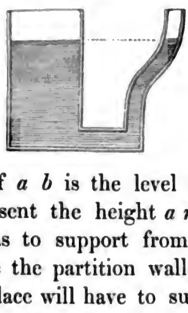
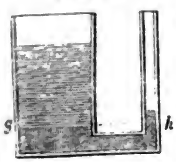


FIG. 69.



According to the principles advanced, the pressure which this partition wall sustains from below is *B. h*, if *B* designate the area of the partition and *h* the height *p v*. If *a b* is the level of the fluid in the wider vessel, and *h'* represent the height *a m*, then the pressure which the partition wall has to support from above downwards is *B h'*. If, now, we suppose the partition wall again removed, the layer of water taking its place will have to sustain on the one side the pressure *B h*, and on the other the pressure *B h'*. Motion will necessarily occur as soon as *h* is not equal to *h'*. There can, therefore, only be equilibrium when *h* and *h'* are actually equal; that is, when the level of the fluid is equally high in both vessels. If the fluids in the two vessels are dissimilar, the level will not be equally high in both.

FIG. 70.



In the tube, for instance, (Fig. 70), there is water in one side, and in the other mercury, the fluids meeting at *g*. Below the horizontal plane passing through *g* there is only mercury, which is perfectly in equilibrium. The column of mercury over *h* has, therefore, to keep in equili-

brium the column of water above g, and, that this may happen, the heights of the columns must be inversely to each other as the specific gravities of the fluids; that is to say, the column of water must be nearly fourteen times as high as the column of mercury, because the specific gravity of water is nearly fourteen times less than that of mercury.

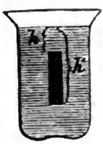
Whatever be the fluids used, the heights of the columns must always bear an inverse ratio to their specific gravities. Thus a column eight inches high of concentrated sulphuric acid will equipoise one of water 14.8 inches high; and a column eight inches high of sulphuric ether will be in equilibrium with a column of water 5.7 inches high.

We often see that heavy bodies move in an opposite way to the direction of gravity; cork and wood, for instance, rise on the surface when they are immersed in water; in the same manner iron rises in mercury, and the air balloon in the air. All these phenomena depend upon the principle known by the name of the *Archimedean principle*, from having been discovered by *Archimedes*.

This principle may be thus expressed:—*A body immersed in a fluid loses a portion of its weight exactly corresponding with the weight of the fluid displaced by it.* Or, to express the same more correctly:—*If a body be immersed in a fluid, a portion of its weight will be sustained by the fluid, equal to the weight of the fluid displaced.*

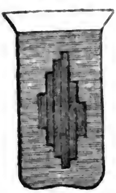
We may convince ourselves of the truth of this principle by means of a simple experiment. Immerse a regular prism vertically in a fluid, as shown at Fig. 71, then every pressure on the sides of the prism is destroyed by an equal and opposite pressure; but the upper surface sustains the pressure of a column of fluid having an equal base with the prism, and the height h. The under surface, however, is pressed upon from below upwards by a force equal to the weight of a column of fluid of the same base, and of the height h'. The heights h and h' differ exactly by the height of the prism, and therefore it is clear that the pressure on the under surface exceeds that on the upper surface by the weight of a column of fluid equal to the volume of the prism. But, as this excess of pressure acts upwards against the gravity of the body, the action of the force of gravity of the body is evidently diminished in the way specified. If, for instance, the base of this prism be one

FIG. 71.



square centimetre, its height ten centimetres, and the upper surface three centimetres below the level of the water, the upper has to sustain a pressure of a column of water whose base is one square centimetre, its height three centimetres; consequently a weight of three cubic centimetres of water, that is, of three grammes. But the lower surface is thirteen centimetres below the level of the water, and has, therefore, to sustain a force acting from below upwards and equal to the weight of a column of water whose base is one square centimetre and height thirteen centimetres, that is, thirteen grammes. If we deduct from these thirteen grammes the amount of the pressure of the three grammes acting downwards upon the upper surface, there remain ten grammes for the force with which the prism is urged upwards by the pressure of the water. But ten grammes is the weight of a column of water of equal volume with the prism. If this prism were of marble it would weigh twenty-seven grammes; but, on being immersed in water, it has to sustain a pressure of ten grammes directed upwards, and, consequently, in the water it will be ten grammes lighter. If, in the place of one prism, we take several together, it is clear that each separate one will lose on being immersed in the water an amount of weight equal to an equal volume of water, and, consequently, the loss of weight sustained by the whole body composed of the several prisms will equal the weight of a mass of water of equal volume to the combined volume of the prisms. As, however, we may imagine any body decomposable into a number of such vertically-placed prisms of very small diameter, the conclusion may be extended to any body we choose to take.

FIG. 72.

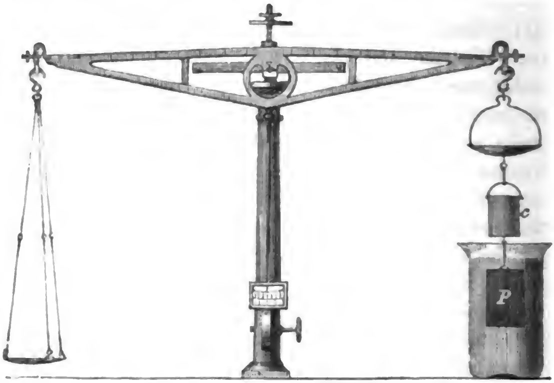


A totally different mode of deduction leads us to the same result. If we suppose the space occupied by the body immersed in water to be filled with water, this body of water will float in the remaining mass of the liquid, neither rising nor sinking. If, now, we assume this body of water to be replaced by another which, with an equal volume, has also an equal weight, this latter will likewise float, its whole weight being sustained by the water in which it is immersed, whence it is clear that a portion of the weight of every immersed body is sustained by the water, and is equal to the weight of the fluid displaced.

We may convince ourselves of the truth of the Archimedean

principle by direct experiment. To one of the scale pans of an ordinary balance (Fig. 73) is attached a hollow cylinder, c,

FIG. 73.



from which is suspended a massive cylinder, *p*, accurately filling the cavity of the former. On the other scale-pan are placed sufficient weights *d*, to equipoise the whole. If, now, the cylinder *p* be immersed in water, it will lose a portion of its weight, and the equilibrium will be thus disturbed; to re-establish this, the cylinder *c* need only be filled with water, which clearly proves that *p* has lost as much weight by being immersed in the water as the contents of the cylinder *c* weigh. But the volume of water in *c* is equal to the water displaced by the cylinder *p*, and the loss of weight of *p* is consequently equal to the weight of the displaced water.

As we have already seen, there would be equilibrium if we could convert into water the immersed body. But this body of water would remain perfectly in equilibrium, whichever way it were turned, round its centre of gravity. The pressure of the surrounding fluid acting from below upwards is, therefore, a force whose point of application corresponds with the centre of gravity of the ideal body of water. This point may be termed the centre of pressure of the fluid.

If, now, this ideal body of water be replaced by any other substance, as, for instance, cork, marble, or iron, the pressure which this body will have to sustain from the surrounding mass of water will be precisely the same as that which the ideal body of water has supported. A body immersed in water is, therefore,

subject to the action of two forces, whose magnitude and point of application we now know. The first force is the gravity of the body acting from above downwards, and whose point of application is the centre of gravity of the body; the second force acting from below upwards is equal to the weight of the water displaced, and its point of application is the centre of gravity of this mass of water. If an entirely submerged body is perfectly homogeneous, its centre of gravity will correspond with the centre of gravity of the water displaced.

This upward pressure of fluids is designated by the term *buoyancy*.

Conditions of equilibrium of submerged Bodies.—For a perfectly homogeneous body submerged in water to keep itself suspended, nothing more is necessary than that its weight be exactly equal to that of the fluid displaced, the position of the body being entirely indifferent: here we have an instance of indifferent equilibrium. In order to prove this by an experiment, let us form a body of any shape from a mass composed of one part of finely pulverized cinnabar, and 226 parts of white wax. The constituents must be well worked together, that the mass may have the requisite uniformity. A body thus composed will float in water, and remain in equilibrium in any position in which we place it. In spirits of wine it will sink, while on a saline solution it will rise and float on the surface.

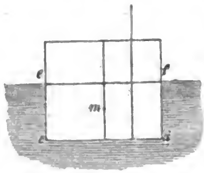
If the immersed body be not homogeneous, so that its centre of gravity does not correspond with the centre of gravity of the water displaced, it may still float in the fluid, if its total weight is exactly equal to the weight of the water displaced; but it can only be in equilibrium if the centre of gravity of the body and that of the water displaced be in a vertical line, and stable equilibrium can only be established if the centre of gravity of the body is in the lowest position.

Conditions of equilibrium of Floating Bodies.—If a body float, its whole weight is equal to the weight of fluid mass displaced by the immersed portion of the body, the condition of the stability of floating bodies differs, however, from that of submerged bodies. A ship, for instance, weighing one million kilogrammes is in equilibrium if it displace 1,000 cubic centimetres of water; and, if its centre of gravity and the centre of pressure of the water lie in a vertical line, we may have a condition of stability even if the centre of gravity do not lie below the centre of pressure, it being sufficient

if it lie lower than another point, termed the *metacentre*. The position of this latter point depends upon the form of the ship, and the position of the centre of gravity upon the manner in which the ship is loaded.

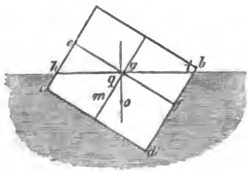
Although a general determination of the *metacentre* would be hardly in place here, we must yet endeavour to give some idea of it:—Let *a b c d* (Fig. 74) be the section of an immersed body, and, for the sake of clearer illustration, let us assume this section to be an elongated parallelogram. If the body swim in a position of equilibrium, it will sink as low as *e f*. The centre of gravity of the displaced mass of water is at *m*, and the centre of gravity of the body lies upon the vertical line, passing through *m*. If it be below *m*, the body will swim stably in every case, for we have a body suspended, as it were, at the point *m* in the water, and whose centre of gravity is deeper than its point of suspension, and consequently a pendulum that oscillates about the position of equilibrium.

FIG. 74.



If the body be changed from the position of equilibrium to the one represented in Fig. 75, the triangle *e g h* is raised out of the water, while *g i f* is, on the contrary, immersed; but, as the quantity of the water displaced must always be the same, whatever be the position of the body, it follows that *e g h* = *g i f*. But the form of the submerged portion differs from what it previously was, and, consequently, the centre of gravity of the displaced mass of water is no longer at *m*, but at another point *o*, whose position must be especially ascertained in each individual case. If we suppose a perpendicular drawn through *o*, it will intersect at a point *g* the perpendicular drawn in the position of equilibrium through *m*; the point *q* is the metacentre. When the centre of gravity of the body lies below *q*, on the line *m q*, the weight of the body acting at *o* will turn it round *o* in such a manner as to make it return to a position of equilibrium. A floating body loses its stability entirely if its centre of gravity lie above the metacentre.

FIG. 75.

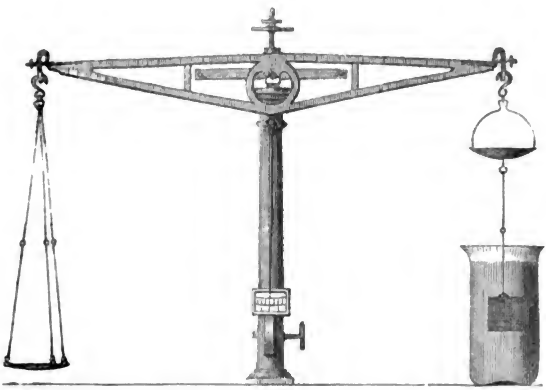


The broader the immersed portion, and the lower its centre of gravity, the greater is the stability of a floating body.

The Archimedean principle affords us excellent means of ascertaining the weight of solid and fluid bodies. In order to compute the density of a solid body, we must know its absolute weight, and the weight of an equal volume of water. But in most cases it is very difficult, and even impossible, to obtain the volume of a body by measuring its dimensions. According to the Archimedean principle, a single experiment gives us, without anything further being necessary, the weight of a mass of water, having an equal volume with the body to be determined; leaving us only to decide the loss of weight on immersion.

In order to obtain this result easily by means of a balance, the instrument undergoes a slight alteration, by which it is converted into a *hydrostatic balance* (Fig. 76). We substitute for one of the

FIG. 76.



usual scale-pans one that does not hang down so low, and to the lower part of which a hook is attached on which the body to be determined may be suspended. When this is done, we may ascertain the absolute weight g of the body by laying weights in the other scale-pan. If we now immerse the body, we must remove a part a of the weight g to restore equilibrium; a is consequently the loss of weight sustained by the body from immersion, and $\frac{g}{a}$ is, therefore, its specific gravity.

Nicholson's Areometer (Fig. 77) may be used to determine the specific gravity of solid bodies, instead of the balance. To a hollow glass or metal body, v, a small heavy mass l (a glass or metal

FIG. 77.

sphere filled with lead) is suspended, and superiorly there is attached to it a fine stem supporting a plate *c*, on which small bodies and weights may be laid. The instrument floats vertically in the water, because its centre of gravity is very low in consequence of the weight *l*. The instrument is so arranged that the upper part of the body *v* projects above the water. If, now we lay the body whose specific gravity we would ascertain upon the plate *c*, the instrument will descend, and by adding additional weight we may easily make it sink to the point *f* marked generally by a line on the rod. We remove the mineral or other substance we have been using, and substitute in its place as many weights as will again make the instrument sink to *f*. If, in the place of the mineral, we have had to lay on *n* milligrammes, the weight of the mineral is equal to *n* milligrammes.

If, in this manner, we have ascertained the absolute weight of the mineral, the *n* milligrammes must be again removed, and the body laid in a basket placed between *v* and *l*. The instrument would now again sink to *f* if the body laid in the basket had not lost weight by being immersed in the water: we must, therefore, lay on the plate the weight *m* milligramme, that the body may be immersed to the mark. In this manner we obtain the absolute weight of the body *n*, and the weight of an equal volume of water *m*; the specific gravity we seek is, therefore, $\frac{n}{m}$.

If, for instance, we have to determine the specific gravity of a diamond, we must lay it on the plate and add sufficient weight to make the whole sink to *f*. If we find after removing the diamond, that we must lay on 1.2 grammes to cause the areometer to sink again to the same point, the absolute weight of the stone would be 1.2 grammes. These weights must be again taken away and the diamond laid in the basket; then, in order to make the instrument sink to *f*, we must add 0.34 grammes more; the weight of a volume of water equal in volume to the diamond is, therefore, 0.34 grammes, and the specific gravity required is $\frac{1.2}{0.34} = 3.53$.

The specific gravity of liquids may also be determined by Nicholson's areometer. As the instrument always sinks so far that its

weight added to the weight upon the plate is equal to the mass of liquids displaced, we may, by the aid of this instrument, ascertain how much a definite volume of water weighs. It is necessary, however, to know the weight of the instrument itself. Suppose this weight to be *n*, we must lay on some additional weight to make the instrument sink to *f*; if we designate this addition by *a*, then is $n + a$ the weight of water displaced.

If we immerse the instrument in another liquid, we must lay on another weight *b* in the place of *a*, to make the whole sink to *f*; *b* will be greater than *a* if the liquid be denser, and less than *a* if it be lighter than water. The weight of the liquid displaced is $n + b$; but its volume is exactly as great as the volume of the mass of water, whose weight is $n + a$, because the areometer has sunk equally deep in both cases.

Suppose the instrument weigh 70 grammes, we must add 20 grammes to make it sink in water, and 1.37, that it may sink to the point *f* in spirits of wine; then the specific gravity of spirits of wine is $\frac{70 + 1.37}{70 + 20} = 0.793$.

The delicacy of the areometer is proportionate to the slightness of stem in comparison with the immersed volume.

It is always a somewhat tedious process to ascertain the specific gravities of liquids with this areometer, and we might effect our purpose as quickly and with much more exactness by means of the balance, in the manner already indicated. But it often happens for practical purposes, that we desire to obtain by a short process the specific gravity of a fluid in as simple a manner as possible, in order to estimate its quality. In such cases, it is quite sufficient to obtain the specific gravity within a couple of decimal places, and this purpose is most readily effected by means of the graduated areometer, which we will now consider.

The graduated Areometer.—By means of Nicholson's *areometer* the specific gravity of a liquid is obtained by a comparison of the absolute weights of equal volumes. But the use of the graduated areometer is based upon the principle that, with equal absolute weights, the specific gravities are inversely as their volumes.

Fig. 78 represents a graduated areometer. It usually consists of a cylindrical glass tube, which is enlarged at the bottom as represented in the drawing. The lower ball is partially filled with

mercury, to enable the instrument to float upright. If we now suppose the instrument to be floating in the water, the weight of the water displaced is equal to the weight of the instrument. If we now immerse it in another liquid, it will sink to a greater or lesser depth, according to whether the liquid is lighter or heavier than water. Supposing that the areometer weigh ten grammes, it will displace ten cubic centimetres when floating in water. If we immerse it in spirits of wine, it will sink so low that the spirits of wine displaced will also weigh ten grammes. But ten grammes of spirits of wine occupy more space than ten grammes of water; the instrument must, therefore, sink so deep that the volume immersed in the spirits of wine shall be inversely to the volume immersed in water as the specific gravity of these liquids.

FIG. 78.

We may now well understand that, if the tube be properly divided, we may ascertain the specific gravity of a liquid by one single easily-conducted experiment. Amongst all the scales that have been applied to the areometer, the one proposed by Gay Lussac is incontestibly the simplest and most efficacious; we will therefore consider it first.

We must suppose the point *a* of the tube of an areometer, to be marked, as being the point to which the instrument sinks in water, and, starting from thence, that a series of lines are so arranged that the volume of the portion of the tube intervening between two marks is $\frac{1}{100}$th part of the volume immersed in the water. If, for instance, we assume that the volume of the submerged portion of the areometer is exactly ten cubic centimetres, then the volume of the portion of the tube intervening between the two marks would be 0.1 of a cubic centimetre.

The watermark *a* is numbered 100, and the divisions are numbered upwards. Areometers thus graduated are designated by the special term *volumeters*. Supposing that the areometer sank in any liquid to the mark 80 on the *volumeter*, we know that 80 parts of this liquid weigh as much as 100 of water; the specific gravity of this liquid is, therefore, to that of water as 100 to 80, and consequently $= \frac{100}{80}$ or 1.25.

If the volumeter were to sink in another liquid to the mark 116, we should find by a similar mode of deduction that the specific gravity of this liquid was $\frac{100}{116}$ or 0.862. In short, *if the volumeter*

ink to a definite point y *of the scale, we find the specific gravity* s *f the liquid on dividing* 100 *by the number observed upon the raduated scale; that is,* $s = \frac{100}{y}$.

The accuracy of such an instrument is increased in proportion o the distance of one mark from the other, and in proportion to he thinness of the tube in comparison with the volume of the vhole instrument. In order to avoid having very long tubes, no olumeter is made applicable to all fluids, there being different ones hat can be used either for lighter or heavier fluids. In the former, he watermark 100 is near the lower; and in the latter, near the ipper extremity of the tube.

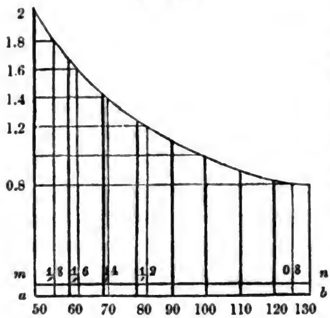
Before the graduation is made, the quantity of mercury in the ›all of the instrument must be so regulated that it will sink in the vater either to a point lying near the lower or upper end of the ube. When this is done, a second point in the scale must be ›btained in the following manner:—

Suppose the instrument to be intended for heavy liquids, and, herefore, having the watermark at the upper end of the tube. We provide ourselves with a liquid whose specific weight is exactly 1.25, and which we can easily obtain by a mixture of water and sulphuric acid, its specific gravity being tested by means of the balance. In this liquid we now immerse the instrument, observing the mark to which it sinks. But the specific gravity 1.25 corresponds to the mark 80 of the *volumeter scale.* This last observed point is, therefore, to be marked 80, and the intervening space to be divided into twenty equal parts; a similar graduation being carried on below the point 80.

If the volumeter be designed for light liquids, and the mark 100 be consequently at the lower part of the tube, we find a second point in the scale on immersing the instrument into a mixture of water and spirits of wine, the specific gravity of which is accurately 0.8. This specific gravity 0.8 corresponds to the mark 125, and we must, therefore, divide the space between this mark and the watermark into twenty-five equal parts. The divisions are generally marked upon a strip of paper, and fastened to the interior of the tube.

The relation existing between the different graduated points of the volumeter, and the specific gravity will easily be understood by looking at the accompanying diagram. The line *a b* (Fig. 79) represents a volumeter scale, ranging from the mark 50 to the

FIG. 79.



mark 130. At every tenth point of division a perpendicular is drawn, on which is marked the length proportionate to the corresponding specific gravity. Thus, if the perpendicular drawn through the point 100 is 1, that through 50 is 2, that through 120 0.83 and so forth, it is of course quite immaterial what unit we choose in the graduation of these perpendiculars.

The summit of these perpendiculars are connected by a curved line, which represents the law connecting the points of the scale and the corresponding specific gravities. The curve ascends the more rapidly as it approaches the lower points of the volumeter scale lying near *a*. From this it is evident that the difference between the perpendiculars drawn through 60 and 70 must be greater than that existing between the equally distant perpendiculars drawn through 120 and 130; or, in general terms, that an equal number of degrees on the lower end of the volumeter scale correspond with a greater difference of specific gravity than on the upper part. It further follows that, if the graduated points of the scale are to correspond to equal differences of the specific gravity, the distance between two points must be greater at the upper than at the lower part of the scale.

Another excellent mode of dividing the areometer scale, proposed also by Gay Lussac, but previously made use of by Brisson and G. G. Schmidt, gives the specific gravities directly. The relation of this scale to the volumeter scale will be easily understood. If we mark on any of the perpendiculars (Fig. 79) the heights 0.8, 1, 1.2, 1.4, 1.6, &c., and draw horizontal lines through these heights to intersect the curve, and from these points of intersection perpendiculars down to the line representing the volumeter scale, or, as is the case in our diagram, to a line *m n*, lying somewhat above that of the volumeter scale, we obtain the degrees upon the scale coinciding with the specific gravities 1.8, 1.6, 1.4, &c. But we here see how unequal are the divisions of the scale, and how much they increase in size from the lower towards the upper parts.

We have here only given the construction of this scale for the

oints from 20 to 20 p. c. of the specific gravity. If we wish to onstruct a scale according to this method, the figure must be rawn according to much larger proportions, and the points from t least 5 to 5 p. c. of the specific gravity must be obtained. The ntervals may then be divided equally without any marked rror.

Another method of constructing these scales has been proposed y Schmidt. Although the specific gravity may be obtained irectly by means of areometers of this kind, the volumeter has reat advantages. In the first place, the completion of a volumeter cale is infinitely easier; owing to the uniformity of the divisions, re may graduate the scale with much greater accuracy, while the alculations that have to be made to learn the specific gravity ccording to the volumeter scale are so extremely simple that they ertainly cannot furnish any grounds of objection to the use of that nstrument.

In a practical point of view, our aim is not so much to learn the pecific gravity of a liquid as to know the point of concentration of a saline solution and the proportion of mixture in a liquid. These points certainly stand in such close relation to the specific gravity, that, if by help of the areometer we can ascertain the specific gravity of a liquid, we may also draw a correct conclusion as to its nature. Special areometers have been constructed for such liquids as are most frequently used, giving the direct proportions of mixture. We will only consider one of the most important of these —the *alcoholometer*.

FIG. 80.

This instrument serves to determine the amount of alcohol in a mixture of water and spirits of wine.

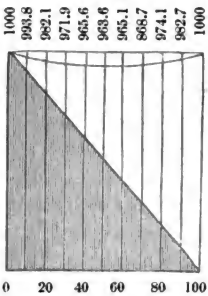
The specific gravity of alcohol is 0.793 if we take that of water as unity; a mixture of water and absolute alcohol will, therefore, have a density falling between 1 and 0.793, and approaching more nearly to either extremity as the water or the alcohol preponderates in the mixture. The density deviates, however, from the arithmetical mean reckoned from the proportions of the mixture.

The reason of this deviation is to be sought in the contraction occurring when we mix water and spirits of wine, and which we will first make evident by an experiment.

If we take a glass tube, such, for instance, as is used in the Torricellian experiment, fill one half with water and the

remainder with spirits of wine (for the Lecture Room, the coloured spirit of wine is preferable), we shall find the liquids do not mix, the spirits of wine floating on the water. When the open end has been closed by a cork stopper, so that no liquid can escape, a mixture of the fluids will occur by the sinking of the water as soon as we invert the tube. When the liquids are perfectly mixed, we see that, instead of the whole tube being full, a vacuum has been formed, and occupying about half an inch of the tube.

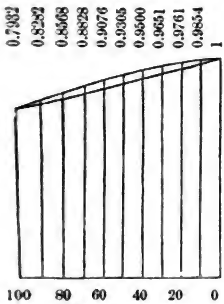
FIG. 81.



The accompanying figure (Fig. 81) represents the laws for the contraction of different proportions of mixture. The perpendiculars drawn at the different points of the horizontal bases of the parallelogram, and passing through its upper side, give the sums of the mixed volumes, the part lying within the shaded portion of the figure showing the volume of the water, and the remainder the volume of the spirits of wine. Thus, the perpendicular line elevated at the point 20 is divided by the diagonal of the parallelogram in such a ratio that $\frac{8}{10}$ths of its whole length fall within the shaded, and the remaining $\frac{2}{10}$ths in the unshaded part of the figure; it corresponds, therefore, to a case where we have a mixture of 80 parts water with 20 parts spirits of wine. But in this case, the mixture forms a volume only 0.982 of the sum of the mixed volumes, on which account the length of 0.982 is marked upon this perpendicular, counting from below (taking the whole length of the perpendicular as the unit). Thus the length 0.965 is marked at the point 60, because 40 p. c. of water mixed with 60 p. c. of spirits of wine coincide with 0.965, the sum of the mixed volumes. The numbers standing over every perpendicular give for each case the exact value of the volume according to the mixture, if the sums of the mixed volumes be 1000. A curve is drawn over the points marked in the way indicated on the different perpendiculars. The vertical distance between each point of this curve from the upper horizontal line represents the amount of the contraction.

From these considerations it follows that the specific gravity of a mixture of water and spirits of wine must always be greater than the computed arithmetical mean. In Fig. 82, 0.793 is the length of the perpendicular drawn through the point 100, if we take the

FIG. 82.



length of the perpendicular from the point *o* as the unity. The former represents the specific gravity of absolute alcohol, and the latter that of water. If we connect the upper points of these two extreme perpendiculars by a straight line, and draw through the points 90, 80, 70, &c., perpendiculars going to this straight line, the length of these perpendiculars would represent the specific gravity of a mixture of 90, 80, 70, &c., parts of spirits of wine with 10, 20, 30, &c., parts of water, if no contraction occurred. But a length is marked upon every perpendicular corresponding to the true density of the mixture. The curve connecting those points in the different perpendiculars, represents the law according to which the density of a mixture of water and spirits of wine changes if the alcoholic contents increase from 0 to 100 p. c.

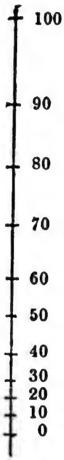
The number standing over each perpendicular gives the accurate numerical value of the specific gravity of the corresponding mixture. If by the numbers 100, 90, 80, 20, 10, 0, we designate those points on an areometer-tube that correspond with the specific gravities 0.793, 0.828, 0.857, 0.976, 0.985, and 1; and if, further, we divide the space intervening between every two points into ten equal parts, which may be done without any great inaccuracy, we obtain a *per-centage areometer* for spirits of wine; that is to say, an instrument by which we can directly read off how many parts by volume of alcohol are contained in a mixture of water and spirits of wine. Such *alcoholometers* have been made in France according to the calculations of Gay Lussac, and in Germany according to those of Tralles, and have been officially adopted, in order that by their aid the alcoholic contents of brandy, spirits of wine, &c., subject to excise duties, might be determined. Fig. 83 shows the main divisions of such an alcoholometer in their true proportions. We see, as we might suppose, that the divisions are of unequal magnitude.

The volumeter may easily replace the alcoholometer, if we only have at hand a table in which the quantity of alcohol corresponding with the different degrees of the volumeter is given.

As may easily be supposed, the alcoholometer is not applicable to any other fluid but the one for which it is designed. In a similar manner areometers have been constructed for giving

accurately the proportions of an acid, a saline solution, &c. As however, such instruments are solely applicable to the single fluids for which they are constructed, it is better to make use of the volumeter, and to seek in the tables constructed for the purpose, the proportions corresponding to the degrees observed on the volumeter.

FIG. 83.



It now only remains for us to mention the older areometric graduations, which, however, are no longer of use for scientific purposes.

Beaumé fixed on a second point, in addition to the watermark, by plunging the instrument into a solution consisting of one part of common salt and nine parts of water. The space intervening between these two points he divided into ten equal parts, which he called degrees, the division being continued beyond the two fixed points. The water point is marked with 0 for liquids heavier than water when the degrees are counted downwards, while for liquids lighter than water, the water point is marked 10, and the degrees are counted upward. It is easy to see that by such an instrument neither the specific weight nor the proportions of a fluid mixture can be ascertained.

Cartier made an unimportant change in Beaumé's scale by increasing the size of the degrees, fifteen of his degrees being equal to sixteen of Beaumé's instrument. However, little benefit may have been derived from this alteration, it has had the effect of handing down his name to posterity, since, in spite of its little value, *Cartier's scale* is very generally known.

In Germany, Meiszner has done much service to areometry, and his Treatise published in 1816 at Vienna, " On the Application of Areometry to Chemistry and Technology," is perhaps the most valuable work that we have on the subject. Meiszner's areometers consist of simple cylindrical glass tubes from six to eight millimetres in diameter, without enlargement at the lower end, which is filled with shot imbedded in fused sealing wax; the scale is at the upper end.

The following table gives a view of the specific gravities of certain bodies, the knowledge of which may frequently prove necessary, or at least interesting.

TABLE OF THE SPECIFIC WEIGHTS OF SOME SOLID BODIES.

atinum—coined	22.100
„ rolled	22.069
„ fused	20.857
„ drawn into wire.	19.267
old—coined	19.325
„ fused	19.253
idium	18.600
ıngsten	17.600
ead—fused	11.352
ılladium	11.300
lver	10.474
ismuth	9.822
opper—malleable	8.878
„ fused	7.788
„ drawn into wire.	8.780
admium	8.694
lolybdenum	8.611
rass	8.395
rsenic	8.308
ickel	8.279
ranium	8.1
teel	7.816
obalt	7.812
ron—wrought	7.788
„ cast	7.207
in	7.291
ntimony	6.712
ellurium	6.115
hromium	5.900
odine	4.948
leavy Spar	4.426
elenium	4.320
Diamond	3.520
Flint glass—French	3.200
„ English	3.373
„ Frauenhofer.	3.779
Bottle Glass	2.600
Plate Glass	2.370
Tourmaline (Green)	3.155
Marble	2.837
Emerald	2.775
Rock Crystal.	2.683
Porcelain—Dresden.	2.493
„ Sèvres	2.145
„ China	2.384
Sulphate of Lime (Crystal)	2.311
Sulphur (Natural)	2.033
Ivory	1.917
Alabaster	1.874
Anthracite	1.800
Phosphorus	1.770
Amber	1.078
Wax (White)	0.969
Sodium	0.972
Potassium	0.865
Ebony	1.226
Oak (Old).	1.170
Box	1.330
Maple—Green	0.904
„ Dry	0.659
Beach—Green	0.982
„ Dry	0.590
Pine—Green	0.890
„ Dry	0.555
Alder—Green	0.857
„ Dry	0.500
Ash—Green	0.904
„ Dry	0.644
Hornbeam—Green	0.945
„ Dry	0.769
Linden—Green	0.817
„ Dry	0.439
Mahogany	1.060
Nutwood	0.677
Cypress	0.598
Cedar	0.561
Poplar	0.383
Cork	0.240

DENSITY OF SOME LIQUIDS AT 32^0 F., UNLESS OTHERWISE SPECIFIED.

Distilled Water	1.000	Bromine	2.966
Mercury	13.598	Sulphuric Acid	1.848

DILUTE SULPHURIC ACID, ACCORDING TO DELEZEUNE, AT 59^0 F.

10 per cent acid	1.066	60 per cent acid	1.486
20 ,,	1.138	70 ,,	1.595
30 ,,	1.215	80 ,,	1.709
40 ,,	1.297	90 ,,	1.805
50 ,,	1.387	100 ,,	1.840

DILUTE NITRIC ACID.

10 per cent acid	1.054	Wines—Claret	0.994
20 ,,	1.111	,, Champagne	0.998
30 ,,	1.171	,, Malaga	1.022
40 ,,	1.234	,, Moselle	0.916
50 ,,	1.295	,, Rhenish	0.999
60 ,,	1.348	Oils—Citron	0.852
70 ,,	1.398	,, Linseed	0.953
80 ,,	1.438	,, Poppy	0.929
90 ,,	1.473	,, Olive	0.915
100 ,,	1.500	,, Turpentine	0.872
Milk	1.030	Alcohol, absolute	0.793
Sea Water	1.026	Sulphuric Ether	0.715
		Sulphuret of Carbon	1.272

CHAPTER IV.

IOLECULAR ACTIONS BETWEEN SOLID AND LIQUID BODIES, AND BETWEEN THE SEPARATE PARTICLES OF LIQUIDS.

Adhesion between solid and liquid bodies.—The phenomena of dhesion occurring between solid and liquid bodies are similar to hose between solid bodies; that is to say, liquids adhere more or ess strongly to the surfaces of solid bodies. If, for instance, we prinkle a few drops of water on a vertical glass plate, they will artly remain hanging to it, instead of dropping down, as would e the case if the gravity of the drops were not counteracted by nother force, namely, the attraction which exists between the articles of the liquids and the surface of the glass.

This adhesion is also the cause of liquids so easily running down he outer walls of the vessels when we would pour them out; and o avoid this, we either rub the outer rim of the vessels with fat, or et the liquid pass along a moistened glass rod.

Capillary Tubes.—It has been already mentioned that the upper urface of a liquid contained in any vessel is horizontal. This, owever, is only true where the molecular action exercises no listurbing influence upon the walls of the vessel. In the vicinity f the walls, deviations from the normal surface always occur.

If one end of a glass tube be plunged into a liquid, the level of he liquid in the tube will never be at the same height with the pper surface of the liquid outside. For instance, when plunged nto water, the column of the liquid rises in the tube (Fig. 84); but f we plunge the tube into mercury, the top of the column of mercury in the tube will be lower (Fig. 85). These phenomena of elevation and depression are known as *capillary phenomena*, and the force producing them as *capillary attraction*, or simply *capillarity*. This force not only acts in the elevation or depression of liquids in tubes, but is at

IG. 84.

FIG. 85.

work wherever liquids are in connection with solid bodies, or among themselves, or where solid bodies are in juxtaposition, or in general where the smallest particles of ponderable matter are in contact.

It is easy to persuade oneself by experiment that the difference of height between the surface of liquids in tubes, and that of the external fluid, increases in proportion to the narrowness of the bore of the tube. If we plunge into water two tubes, of which one has twice as large a diameter as the other, the water will rise twice as high in the narrower tube; if we plunge them into mercury, the liquid will be depressed twice as low in the narrower tube.

The difference of the level of liquids within and without the tubes is inversely as the diameter of the tubes. The height of the raised columns depends in the above-given manner upon the diameters of the tubes, but, if the walls of the tubes have been wetted, their thickness and substance are of no importance; on the other hand, the height depends especially upon the nature of the liquid. The following is the elevation in a tube of one millimetre in diameter for three different liquids :—

Water	29.79 millimetres.
Alcohol (sp. gr. 0,8135) . .	9.15 „
Oil of turpentine . . .	12.72 „

We must not omit to mention that when a liquid rises in a narrow tube, the surface of the liquid column is always concave (Fig. 86), forming a hollow hemisphere having the diameter of the tube. If, on the contrary, there be a depression, the top of the liquid will assume a convex form (Fig. 87). These forms are essentially dependent upon the elevation or depression, for if we pass any fatty substance over the minor walls of the tube, and then place it into water, we obtain a convex meniscus, exactly as if we had immersed an ordinary glass tube in mercury. It follows, therefore, that the differences of the level depend upon the form of the meniscus, and, consequently, that all accidental causes which hinder the meniscus from assuming its regular form, also modify the height of the columns. If, for instance, a tube be not perfectly smooth and clean internally, indentations will appear at the border of the

FIG. 86.

FIG. 87.

eniscus, and we then obtain, on frequently repeating the experi-ient, very various results.

The power of blotting-paper in taking up liquids, the action of ie wicks of candles and lamps, the efflorescence of saturated olutions, &c., all depend upon the action of capillary tubes. The essels of plants conveying the sap upwards from the roots are emarkably minute, and act on this principle.

Connection between the particles of a Liquid.—Although liquids ave no independent form, and although their separate particles dmit of being most easily displaced, the connection existing etween them does not cease, as we see exemplified in the case of ie formation of drops. If we pour water upon a surface strewed ith lycopodium seed, or mercury, into a porcelain vessel, drops lmost spherical will be formed. If no connection existed between ie separate particles of the water and the mercury, they would fall sunder like dust; in slowly pouring liquids from any vessel, they ill not fall in separate drops; such a drop only falling if its eight be sufficiently great to effect at once a separation from the emaining mass of the liquid.

The cohesion existing between the separate particles of a liquid an be directly measured. If a solid disc be placed upon the urface of a liquid, it can no longer be lifted up in an horizontal osition with the same force as when hanging freely in the air; a greater or smaller additional force being necessary to draw it up. We make use of the balance in order to measure this force. On he one side we hang an horizontal disc, and on the other we lay a alancing weight to establish equilibrium. If the whole be equi-oised, we approximate the surface of a liquid to the under part of he disc until they meet, and then, without shaking the balance, ve add weights to the opposite side, remarking the quantity necessary to separate the liquid from the disc.

In order to remove a glass disc of 118^{mm} diameter, different weights are required for different liquids. As for instance:—

Water	59 grammes.
Alcohol	31 ,,
Oil of turpentine	34 ,,

A disc of equal diameter, and constructed either of copper or any other substance, wetted by a liquid, yields precisely the same

results. Adhesion is, therefore, like capillarity, independent of the nature of the solid bodies, and depends only upon the nature of the liquids. It is easy to see the reason of this, for on drawing it up there always remains a layer of the liquid on the disc; the liquid, therefore, has not been separated from the disc by the preponderance of weight on the other side, but the molecules of the liquid have been severed from each other, and the cohesion of the liquid has been overcome. The experiments adduced yield, therefore, a measure for the cohesion of liquids, and for the attraction existing between their particles, and we thus see how considerable is this attraction, and that it changes with the nature of the liquids.

If the upper surface of the disc be not moistened with the liquid, as for instance, is the case when we place a glass disc on mercury, the extra weight effecting the separation no longer expresses the cohesion of the liquid.

It is necessary to use a force of about 200 grammes to raise a glass disc of the above dimensions. It follows, therefore, that, even when a solid body is not moistened by a liquid, a greater or smaller attraction will still exist between the molecules of the liquid and those of the solid body, only in this case the cohesion of the liquid is greater than the adhesion between the liquid and the solid body.

The phenomena here treated of may be considered, in a theoretical point of view, in the following manner:—Mercury forms spherical drops upon paper, and water upon an unctuous or sprinkled surface.

This phenomenon is usually explained by the universal attraction of all molecules to one another, on the same principle that we explain the spherical formation of the heavenly bodies. But this explanation is not admissible, since molecular attraction acts very differently from universal gravity; and since, from its acting only at imperceptible distances upon contiguous molecules, it cannot be so condensed as to form a central point of attraction similar to the central point of gravitation of the planets. The following seems to be a more correct mode of elucidating the subject:—

The molecules of a liquid must remain at such a distance that attraction and repulsion shall neutralize each other. This is only possible when the molecules are so placed in regular layers that each molecule is surrounded by twelve others, something in the manner that cannon balls of equal size are wont to be ranged.

his arrangement remains also undisturbed where the liquid terminates in a level surface. Every molecule is subject to perfectly qual actions from all sides, and all the molecules are perfectly quidistant one from the other. Such an arrangement may be rmed the normal arrangement of the molecules. If a part of the miting surface be curved, the reciprocal apposition of the molecules can no longer remain the same; and such a deposition may e termed abnormal.

As soon as the normal position of the molecules is disturbed by ny external force, the hitherto perfect equilibrium of the whole ill be disturbed, a tension will arise, striving to restore the isturbed parallelism of the layers, and bring back the particles of ie liquid to their normal position as soon as the disturbing cause eases to act. If we plunge a rod moistened by a liquid into the ame, we may, by slowly drawing it out, form an elevation which ill immediately be restored to a plane surface on entirely removing he rod.

This certainly can only be the consequence of gravity; but he same thing occurs in the reversed position of the plane. If e fill with water a tube not exceeding three lines in diameter, nd having one end open, we may revolve it without the water scaping. It forms a hanging plane, from which, as in the ormer instance, then arise elevations, which, after separation, n opposition to the action of gravity return to the plane urface.

A liquid strives, therefore, to terminate in a plane surface; but a nass free on all sides cannot be surrounded by one single plane. If it were bounded by plane surfaces, the edges would be soon lattened by the tension of the molecules; but, if the mass were bounded by a curved surface, whose curves were not equal on all sides, a stronger tension would naturally also occur at the more strongly curved parts of the surfaces, tending to the perfect sphericity of the whole. The roundness of the air-bubble depends upon the same principle. The superficial molecules of a perfectly free liquid compose, therefore, a network, forcibly compressing the minor part. If we make a soap-bubble, it will retain its size as long as we keep the opening of the tube closed, but, as soon as this ceases to be done, the bubble will diminish more and more. If the air in the bubble were not compressed by the enclosing liquid, and if it were not denser than the surrounding atmosphere, it would remain in the

bubble, and not be forced into the tube against the atmospheric pressure of the air.

If mercury is put into a glass, it will stand off from the sides of the vessel, although, perhaps, not perceptibly; if, however, we add water or olive oil, either will fill the interval. In badly prepared barometers, air will also force itself through this interval into the Torricellian vacuum. The mercury forms a large drop lying free in the glass, and its form depends upon the walls of the vessel. It terminates superiorly in an horizontal surface, which, however, cannot reach to the sides of the vessel, owing to the sharp edge of the drop having been rounded off, as we have before said.

If a drop of mercury be poured into a perfectly cylindrical glass tube placed horizontally, the drop will form a cylinder rounded at either end. No motion can, however, arise, as the convexity is equal at both ends.

But, if the tube be conical (Fig. 88), the mercury will be more curved at the narrower end; the tension of the abnormally placed molecules is, therefore, greater here than on the other side, and the consequence of this preponderating tension is, that the mercury moves to the wider end.

FIG. 88.

If we entirely fill a narrow tube with mercury, and place it horizontally, letting the one end communicate with a drop of mercury at the extremity of the tube, the latter will increase until the mercury at length entirely leaves the tube, and is collected in one large drop. The reason of this is easily understood. By the strong curvature of the convexity at the end of the cylinder of mercury, there arises on this side a far stronger pressure on the mass than on the side of the drop.

If a glass tube be plunged vertically into mercury, the liquid will be deeper within than without the tube, as the strong convexity of the cylinder of mercury acts depressingly in the tube. It is also clear that the narrower the tube, the greater will be the depression.

If a liquid adhere to the walls of the vessel and wets them, it can no longer, as in the former instance, be regarded as a large drop; the upper surface cannot, therefore, as there, assume a convex form. The molecules of the walls of the vessel in contact with the liquid act upon the latter as the molecules of the liquid upon one another. The solid walls of the vessel are, therefore, only to

be considered as a rigid continuation of the liquid. The air above the liquid in the vessel must, therefore, be regarded as a bubble, bounded inferiorly by the liquid, and on all sides by the walls of the vessel. If the surface of the liquid were perfectly even, the bubble would have a sharp edge where the fluid and the walls of the vessel came in contact, which would immediately be rounded off by the mutual attraction of the molecules of the wall and the fluid; as, however, the molecules of the vessel are solid, the surface of the liquid must necessarily assume a concave form, while the molecules of the liquid ascend the sides of the vessel. In the bubble, however, the tension of the abnormally placed molecules of water exercises a pressure upon the enclosed air; and then the concave surface of the liquid also exercises an upward pressure against the air of the bubble. A drop of water in a horizontal cylindrical glass tube will form a cylinder concave at both ends, and stationary, owing to the concavity being equal at both ends. If the tube be conical, the one concavity must necessarily be more strongly curved than the other, and, by the preponderating tension of the stronger curved extremity, the water will be drawn towards the narrower part of the tube (Fig. 89). In the same manner we may easily explain, by the action of concave surfaces, the rising of water in a tube plunged vertically into that liquid.

FIG. 89.

If a hollow glass sphere swim on water, the liquid will begin at a distance of more than six lines to rise against the ball. If now we put a second glass sphere into the water, at about one inch from the former, the balls will begin to approach each other, at first slowly, then more and more rapidly, until they finally strike one another (Figs. 90 and 91). If both balls had been fixed, the

FIG. 90.

FIG. 91.

water between the balls would have risen, in consequence of its striving to come to a level; but, as they are moveable, the adhering water-surfaces sinking from the action of gravity must draw together the balls between which they were interposed.

Elasticity of Liquids.—Liquid bodies are also in some respects elastic, for they allow themselves by means of a very strong pressure to be reduced to a volume somewhat smaller than their original mass, and resume their former volume on the removal of the pressure. *Oersted* first, and subsequently *Colladon* and *Sturm* have made experiments upon the compressibility of liquids, but we should be drawn into too wide a digression were we to enter fully into a description of what they have done. The pressure of one atmosphere (an expression that we will explain in the proper place) compresses mercury to about three, and water to about forty-eight millionth parts of their volume.

CHAPTER V.

OF THE EQUILIBRIUM OF GASES, AND OF ATMOSPHERIC PRESSURE.

Air is a body that does not act immediately upon the senses as solid and liquid bodies, but manifests itself by so many phenomena upon the land, and over the waters of the earth, that it will be unnecessary to seek for other proofs of its existence. There are thunderstorms in every climate, and storms on every sea; the air, therefore, everywhere surrounds the whole globe of earth, forming at all points a layer of great thickness; for clouds driven by the winds pass alike over plains and hills. Above the clouds we see the glorious colour of the sky, evincing the height of the air as the colour of the ocean does the depth of its waters. If there were no air, the sky would be without colour and brightness, appearing but as a perfectly black vault, in which the stars would appear with the same splendour by day as by night. This vast mass of air spread over the earth, and stretching high over the summits of the loftiest mountains, bears the name of the *atmosphere.* The highest peak of the Himalaya scarcely stretches five miles above the level of the sea, while the air rises to a height at least six or seven times loftier.

The chemical discoveries of the past century have taught us to know many bodies possessing the same physical properties as the air, although very different in their nature. They were termed *airs,* and were spoken of as *mephitic, combustible,* and *fixed airs.* In the present day, they are called *gases, gaseous bodies,* or *elastic fluids.*

Gases are, like liquid bodies, subject to two different forces, gravity and molecular forces.

At a very remote period, even before the time of Aristotle, it

was conjectured that air had weight. This truth was, however, first proved by Galileo, in 1640, and confirmed somewhat later by the beautiful experiments of Torricelli. The heaviness of the air may be directly proved by the following experiment:—We take a balloon provided with a cock, and from which the air has been removed by means of an air-pump; hang it on one arm of a balance, and lay sufficient weight on the opposite side to establish equilibrium. If now we turn the cock, the balloon will again be filled with air, the equilibrium disturbed, and the balance inclined to the side of the balloon. We must now again lay on sufficient weight to equipoise the whole, and this will be precisely as much as the air in the balloon weighs. For a balloon of one litre, the difference of weight amounts to more than one gramme, from whence it follows, at a rough estimation, that under ordinary circumstances one litre of air weighs more than one gramme; that is, that water is not quite 1,000 times so heavy as common air.

Instead of a balloon with a cock, we may use the following cheap arrangement, which has, further, the advantage of weighing much less under an equal volume than the former. We must take a balloon of not very thick glass, and not a very narrow neck (Fig. 92). The neck must be carefully closed with a tightly-fitting cork, perforated through the middle with an opening about two millimetres in diameter. The cock must now be tied down with oil silk, as seen in Fig. 92, and on a larger scale in Fig. 93. In this manner the inner part of the balloon is completely secured from the access of external air. Near the part covering the opening of the cork, we make two cuts into the oil silk, as seen in Fig. 93, and then the balloon is to a certain extent closed with a valve through which air may escape from the balloon, but cannot enter into it. In making this experiment we first weigh the balloon while full of air; we then bring it under the receiver of the air-pump, when, on exhausting it, the air in the balloon will also be removed; when thus emptied it must be reweighed, when we shall find that it has become lighter.

FIG. 92.

FIG. 93.

Molecular forces act very differently in gases from what they

do in solid and liquid bodies. We have seen that these forces hold firmly together the molecules of solid bodies, so that they cannot change their respective positions. They also hold together the molecules of liquid bodies, but only in such a manner as to afford them more freedom in displacing each other in all directions. In gases, however, molecular forces act repulsively, the molecules of gaseous bodies having a tendency to move reciprocally away from each other, and that to so great an extent that nothing but external impediments can hinder their further expansion. The air contained in a vessel presses, therefore, continually against its sides.

This tendency in air to expand will be easily shown by the following experiment:—We lay under the receiver of the air-pump an animal bladder containing but little air, and, therefore, wrinkled, having its opening tightly secured. After a few strokes of the piston, the bladder becomes inflated, and at last is tensely stretched, as if air had been violently injected. If we suffer the air to return to the receiver, the bladder will again shrivel up. The air enclosed in the bladder has, therefore, really a tendency to expand, but meets with opposition from the surrounding air. Instead of a bladder we might have placed a thin, firmly-corked glass under the receiver, when the stopper would either have been forced out, or the glass would have been burst, provided the cork were not too firmly placed, or the glass too strong. This pressure exercised by the air upon the sides of the enclosing vessel is what we term its *elasticity*, *power of tension*, or *force of expansion*.

A feather only manifests elasticity if we compress it; it loses its tension as soon as it returns to its original condition. But air has always an expansive force; it cannot be said to have any original volume, for it always strives to occupy a larger space. If we were to admit one litre of common air into a *vacuum* of several cubic metres, it would distribute itself equally throughout the whole space, and would always manifest a tendency to expand, exercising, consequently, a pressure upon the enclosing walls.

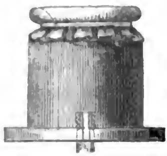
The construction of the air-pump, an instrument to which we have already repeatedly alluded, and which we purpose now describing more fully, depends upon the tendency manifested by the air of occupying as large a space as possible. If the air had no power of tension, no elasticity, in the sense we have ascribed

to the words, it could not distribute itself out of the receiver of the air-pump; without its tendency to expand, the air could not escape from the balloon, even if we removed the weight of air pressing from without upon the valve.

It follows, from the expansive force of gases, that they cannot be bounded by a free even surface, as is the case with fluids. Two forces, gravity and the force of expansion, act upon the air of our atmosphere and counterpoise each other. By gravity the particles of the air are attracted to the earth: this force, therefore, exercises a tendency to condense the air upon the earth's surface, which is counteracted by the force of expansion. The atmosphere is, therefore, probably limited, as the expansive force diminishes so much at a certain degree of rarefaction, that the gravity of the particles of air is alone sufficient to hinder a further removal from the earth.

Pressure of the Air.—If the common conditions of equilibrium be satisfied, we may prove by direct experiment that all the under layers of air are pressed upon by the upper, and that the amount of this pressure varies as we ascend more and more above the level of the sea.

FIG. 94.



Let us place a glass cylinder, with somewhat thick sides, upon the plate of the air-pump, and cover the vessel with a bladder tightly stretched, and firmly tied over the top. The bladder suffers an equal pressure on both sides, and forms, therefore, a level surface. If, now, by any means, we force additional air into the cylinder, the bladder will be arched outwards; but if, on the contrary, we remove any of the air from the cylinder, the external pressure of air will preponderate, and force the bladder inwards. The latter may easily be shown by means of the air-pump. After the first few strokes of the piston, the bladder will already be curved downwards, and the more we exhaust the air the more this curvature increases. If we strike the bladder with any sharp body when it is thus stretched, it will be torn in a thousand pieces, with a noise like the report of a pistol. This sound is produced by the air forcing itself in; and we may thus form some idea of the amount of the pressure of air resting upon the bladder.

If we had so far altered the experiment as to have placed the bladder in an oblique position, or made the pressure of air act

from below, we should have obtained the same result, as the air presses in all directions in an equal manner.

This experiment appears very striking, when we think that the air in a room is able to exercise so enormous a pressure. This effect cannot arise from the weight of a column of air resting upon the bladder, and stretching from thence to the ceiling of the room, for even a column of water of this height could not produce such a result. If the experiment were made in the open air, the bladder would evidently have to sustain the pressure of a column of air whose height is equal to the height of the whole atmosphere. The same pressure acts in a room, for the air within the room is acted upon by the whole pressure of the atmosphere.

Measurement of Atmospheric Pressure.—As the air surrounds the whole earth, it presses upon everything as upon the bladder, upon the land as upon the ocean. If we plunge one end of a tube into a vessel filled with water, the fluid will rise as high within the tube as without, for the pressure of the air in the tube acts precisely the same upon the level of the fluid as without the tube. But if we abstract a portion of the air from the tube, the fluid will continue to rise as long as we remove the air. By this exhaustion the air within the tube is diminished, while the external pressure of the air remains the same. The preponderance of the external pressure of air raises the fluid within the tube, until the weight of this raised column of water equipoises the preponderance. If we entirely exhaust the air in the interior of the tube, the water must rise (provided the tube be high enough), until the weight of the raised column of water is equal to the weight of a column of air of the same base reaching to the limits of the atmosphere. In this manner we may ascertain the weight of a column of air, whatever be its height.

We have to thank the mechanicians of Florence for the first germ of the discovery of this important law. On trying to raise water above thirty-two feet in a suction pipe, they found to their great surprise that the fluid would not rise beyond that altitude. The rising of a fluid was explained at the time by saying that *Nature abhors a vacuum;* but this reason did not satisfy Galileo, who, on hearing of the observations made by the pump-makers, at once came to the conviction that the gravity of the air was the true cause of the phenomenon. His pupil, Torricelli, gave convincing proofs of the truth of this conjecture, and arrived at nearly the following results. In order that two different columns of

fluid should be equipoised, it is necessary that their heights must be inversely as their densities. Mercury weighs nearly fourteen times as much as water. If, now, the atmospheric air can support a column of water thirty-two feet in height, it must also, according to the above view, be able to sustain a column of mercury $\frac{32}{14}$, that is, of twenty-eight inches in height. The experiment is easily made. We fill with mercury a glass tube of about thirty inches in length, and closed at one end, and, holding the finger over the open end, invert it. If, then, we plunge the end closed by the finger into a vessel with mercury, and then remove the finger,

FIG. 95.

the mercury will immediately sink some inches, until the elevation of the mercury in the tube is as much beyond the level of the mercury in the vessel as follows from the above considerations. The column of mercury in the tube is to be regarded as an equipoise to the pressure of the atmosphere. This apparatus constitutes the *barometer*. The *vacuum* above the column of mercury is termed the *Torricellian vacuum*. We may express the above results more correctly. The vertical height of the level *s* in the tube above the level *a b* is called the *height of the barometer*. It is not the same in all places, or at all times. In the vicinity of the sea it averages 76 centimetres, or, what is nearly the same thing, 28 Paris inches.* Such a column of mercury, with a base of 1 square centimetre, has in cubic contents 76 cubic centimetres. As, now, 1 cubic centimetre of mercury weighs 13.59 grammes, the pressure of the column on its base is 76×13.59 grammes=1,033 kilogrammes. The column of atmospheric air, which at the level of the sea rests upon a base of 1 square centimetre, presses, therefore, on its surface with a weight of 1,033 kilogrammes.† We may carry this computation still further, and determine the weight of the whole mass of air composing the atmosphere. For instance, whatever number of cubic centimetres the earth's surface contains, so many times 1,033 kilogrammes does the mass of the air weigh.

Construction of the Barometer.—Barometers have had various

* Very nearly thirty English inches.—Tr.

† This is equivalent to a pressure of fifteen pounds on 1 square inch.—Tr.

FIG. 96.

forms given to them, according to the several uses for which they are intended. Fig. 96 represents the ordinary barometer, consisting of a tube which is curved at the bottom, and terminates in a wide vessel, the whole being secured to a board. The graduated scale is generally made of metal. If the vessel be somewhat wide in comparison with the bore of the tube, the oscillations of the column exercise but little influence upon the level of the mercury in the vessel, so that in cases where extreme exactitude is not requisite, this level may be regarded as constant. In these barometers, which cannot be used in very nice observations, the scale is generally confined to the upper part of the instrument.

In travelling, the *syphon barometer* of Gay Lussac is almost exclusively made use of, owing to the accurate results it yields, the facility of observing it, and, above all, the ease with which it can be carried. The open limb has only a capillary aperture of sufficient size to admit the air freely, and too small to allow of the mercury escaping. We may, therefore, invert it, without fear of losing the mercury.

FIG. 97.

In these barometers, the lower surface of the mercury which is exposed to the pressure of the atmospheric air has no fixed position. The zero point from which the height of the column of mercury must be measured rises and falls. For the sake of safe and convenient transportation, the *syphon barometer* is generally fastened into a wooden case (Fig. 97), forming a staff or rod when closed.

Whatever may be the form of the barometer, certain conditions must be satisfied if the instrument is to give the exact amount of atmospheric pressure. The height of the column of mercury must admit of being accurately measured, which can only be done if the tube be in a perfectly vertical position. The degrees of the scale are either marked upon a slip of brass inserted in the board to which the tube is secured, or are engraved upon the tube itself.

The space above the column of mercury must be perfectly *free of air*. The only way of effecting this object is by boiling the mercury in the tube, and thus

removing all particles of air, and moisture adhering to the sides of the glass. This process is one requiring much practice and skill. We may detect the presence of a particle of air in the *Torricellian vacuum* by the space not becoming entirely filled with mercury on inverting the tube, a little bubble of air remaining in that case at the top of the tube. The larger the volume of the empty space, the less importance is to be attached to the defect.

Finally, the mercury must be perfectly pure, and the bore of the tube not too small. If the tube be too narrow, the adhesion and the friction of the mercury exercise so important an effect upon the sides of the glass, that the column of mercury often remains standing higher or lower than it ought according to the height of the pressure of the air. If in such cases we strike the barometer, we may see the column of mercury instantly rise or fall, according to its previous position, as the hindrance to the motion has been overcome by the blow.

Of the fluctuations of the barometer dependent upon the changes of the weather we will speak further.

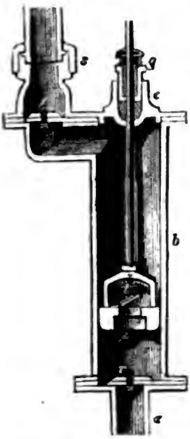
Amount of Atmospheric Pressure.—We have already mentioned what must be the amount of pressure of air corresponding to 760 millimetres of the barometer. In the same manner the amount of atmospheric pressure may be reckoned at every height of the barometer. The results are given in the following table :—

Height of the Column of Mercury.	Pressure upon One Square Metre.	Height of the Column of Mercury.	Pressure upon One Square Metre.
Millimetres.	Killogrammes.	Millimetres.	Kilogrammes.
500	6793	650	8381
510	6929	660	8967
520	7065	670	9105
530	7201	680	9238
540	7336	690	9374
550	7472	700	9510
560	7608	710	9646
570	7744	720	9782
580	7880	730	9918
590	8016	740	10054
600	8152	750	10189
610	8287	760	10330
620	8423	770	10461
630	8559	780	10597
640	8695	790	10733

The surface of the human body measures about 1 square metre; e see, therefore, from these calculations the enormous pressure e constantly have to sustain, and yet we do not feel it, owing its acting uniformly on all sides, and because the air within ur bodies perfectly equipoises the external pressure. On the summit f Mount d'Or, the barometric column is only 600 millimetres; weight of 2,173 kilogrammes is, therefore, gradually removed rom the traveller as he ascends higher and higher up the mountain, nd still more on reaching the summit of Mount Etna or Lebanon. he diminished pressure of the air at higher elevations produces ie most peculiar effects upon the human body, which is not made endure so rarefied a state of the atmosphere. Even persons in ood health experience lassitude, indisposition, and oppression.

Pumps.—A number of phenomena, of which we are daily itnesses, admit of being explained by the pressure of the air. f we suck the upper end of a tube immersed in water, the liquid will ise in the interior of the tube, owing to the air in the upper part being arefied by the action of sucking, and the pressure of air acting on he external level of the water forcing the liquid into the tube. We nay produce a similar rising of the water by inserting a piston in the nterior of the tube, by the working of which the air will be likewise arefied. Upon this principle depends the construction of pumps.

FIG. 98.

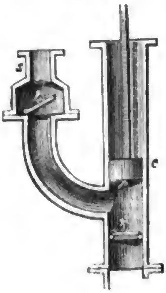


The Suction Pump consists of a suction or feeding pipe *a* (Fig. 98), a cylinder *b*, a piston *p*, an upper pipe *s*, and three valves *r*, *t*, and *l*, opening upwards. The valve *r* is at the bottom of the cylinder, *t* is in the piston, and *l* in the lower end of the upper pipe. The suction-pipe plunges into the water we wish to raise, and the piston-rod moves air-tight through the box *e*. When, on the first movement, the piston is raised, *t* closes, but *r* and *l* are open; *l* owing to the condensation of air above the piston, and *r* owing to its rarefaction below the piston. As the pressure of air in the suction-pipe diminishes, the water rises in consequence of the preponderance of the external pressure. The lower valve closes as the piston descends. The air in the cylinder below the piston is compressed, and, opening the valve *t*, passes through the piston into the upper part of the cylinder.

On the second elevation of the piston, the water again ascends higher in the suction-pipe, while a quantity of air is again expelled through the valve *l*. At last, after a certain number of strokes of the piston, the water ascends above the valve *r* and lifts up the valve *t*. Then, all the air being expelled from the pump, every valve is raised by the water alone. Every time the piston descends, a quantity of water passes through the valve *t*, and at each stroke a fresh supply is raised into the upper pipe and the suction-pipe. The force expended in raising the piston is partly lost in overcoming the friction, and in counteracting the pressure of a column of water whose base is equal to the surface of the piston, and whose height is equal to the vertical distance between the orifice at which the water escapes, from the upper tube over the level of the liquid, into which the suction-pipe is immersed. To make a pump efficient, the water must be able to reach the first valve *r*. The position of this valve depends upon the degree of rarefaction which can be produced between the valves *t* and *r*. If there were no space between *r* and *t* at the lowest position of the piston, an absolute *vacuum* might be produced between these two valves, and the valve *r* should be placed thirty-two feet above the level of the water of the reservoir. But, as it is impossible entirely to avoid interstices occurring below the piston, the valve *r* must not be elevated quite thirty-two feet above the level of the reservoir. Care must, however, be taken to make the space as small as possible in comparison with the contents of the cylinder. If, for example, the space occupied one half of the contents of the cylinder (excepting that filled by the piston), we could only rarefy the air between *r* and *t* to half the pressure of the atmospheric air, and consequently the valve *r* should not be elevated more than sixteen feet above the level of the water in the reservoir.

The Suction and Forcing Pump (Fig. 99) consists of a suction-pipe *a*, an upper pipe *s*, a cylinder *c*, and a heavy piston *p*; it has only two valves, *r* and *l*. On raising the piston, the water forces itself through the valve *r*; on lowering the piston, *n* is closed, and the water raised up is forced through *l*.

FIG. 99.



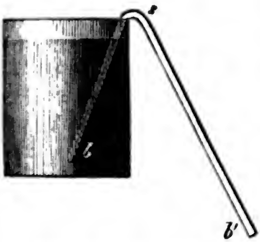
The Syphon.—If we fill a drinking glass having a smooth edge (cut glass is the best) with water, cover it with a paper, and invert it, the water will not run out, the pressure of the air acting on the under surface of the paper, and thus hindering the escape of the liquid. The

paper is only so far necessary as to enable us to invert the glass, and prevent the water from running out at the sides, and air-bubbles entering the vessel. When the lower opening is so small as to leave no fear of the liquid thus running out, as is the case with the form of syphon depicted in Fig. 100, the paper is unnecessary. This syphon is a common tubular vessel, constricted above and below, and open at both extremities. If we plunge it entirely into a liquid when both orifices are open, it will be entirely filled, and, placing the thumb over one opening, we may lift the syphon up without any of the fluid contained in it escaping.

FIG. 100.

The *common syphon* (Fig. 101) is a curved tube, *b s b′*, whose legs are of unequal length. If the shorter leg be plunged into a liquid, and the whole tube filled, the liquid will continue to run out at *b′*, the end of the longer leg lying lower than *b*; we may, therefore, easily empty a vessel by means of a syphon. The action of the syphon admits of a ready explanation. On the one side the column of water *s b′*, and on the other the column of water from *s* to the level of the liquid in the vessel have a tendency to fall, owing to their gravity.

FIG. 101.

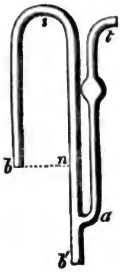


The gravity of the two columns of water in the different legs is, however, opposed on both sides by the pressure of air acting on the one side on the aperture *b′*, but on the other on the surface of the water in the vessel, and thus hindering the formation of a *vacuum* in the interior of the tube, which would necessarily be formed at *s* if the columns of water ran down on both sides.

As the pressure of air acts alike strongly on both sides, equilibrium would be established if the columns of water were equally high in the two legs; that is, if the opening *b′* were at the elevation of the level of the water in the vessel; as soon, however, as *b′* lies deeper, the column in the leg *s b′* preponderates, and, in proportion as the water escapes there, water is again forced into the tube on the other side by the pressure of the air, so that the liquid continues to escape until the level of the water in the vessel has

fallen to the height of the opening b', or the opening at b has been set free.

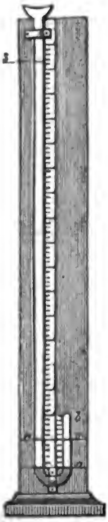
FIG. 102.



A suction-tube, $a\ t$ (Fig. 102), is sometimes attached to the syphon to make it more useful and efficient. We fill a common syphon by sucking at b'; as this process, however, is objectionable, owing to the difficulty of preventing the fluid from entering the mouth, which might be very dangerous in some cases, as, for instance, in emptying a vessel of sulphuric acid, a suction-tube is indispensably necessary, as, by means of this, we may fill the whole leg $s\ b'$ by sucking at t, without the fluid entering the mouth, if we close the tube at b'. The escape of the fluid begins as soon as we again open the end b' of the tube.

Mariotte's Law. The volume of gases is inversely proportional to the pressure to which they are subjected.—To prove this fundamental law by experiment, we take a curved cylindrical tube whose shorter leg is closed above, while the longer one remains open.

FIG. 103.



At first we pour a little mercury into the tube, and then incline it a little that the air may escape from the shorter leg. By this means we can easily contrive that the mercury shall stand equally high in both legs. Then the air enclosed in the space $a\ b$ (Fig. 103) is exactly counterpoised by the pressure of the atmosphere. If we again pour mercury into the open leg, the pressure to be sustained by the enclosed air is increased, and the latter is compressed within a smaller space. If the mercury rise in the shorter leg to the point m, half way between a and b, the air will be compressed to the half of its former volume; if now we mark on the longer leg the point n at an equal height with m, and measure how high the mercury has risen above n in the longer leg, we shall find that the height of the column of mercury $s\ n$ is exactly equal to the height of the barometer; the air enclosed in $b\ m$ has, therefore, to support the pressure of two atmospheres. If the open leg of this apparatus were long enough, we might show in the same manner that a pressure of three or four atmospheres would compress the

enclosed air to one third or one fourth of its original volume. Arago and Dulong have shown that for atmospheric air this law does not vary in its application at least up to a pressure of twenty-seven atmospheres.

By this experiment the correctness of Mariotte's law is proved from the pressure of one atmosphere to the pressure of twenty-seven atmospheres; while for a pressure of less than one atmosphere we may confirm the principle by the help of the apparatus about to be described (Fig. 104). A somewhat wide glass tube, terminating above in a wider vessel, and closed below, is so placed in a frame as to stand vertically. It is filled with mercury to about the line *c n*. We now fill a barometer-tube (as in the Torricellian experiment before described) with mercury, leaving, however, a space of three to five centimetres empty. If we now close the aperture with the finger, and invert it, the air-bubble will ascend into the upper part of the tube.

FIG. 104.

If, now, as in the Torricellian experiment, the lower end of the tube enters the mercury of the vessel *c n*, and we remove the finger from the tube, the column of mercury in the barometer-tube will fall to a certain point. But we shall immediately observe that the summit of the column of mercury does not stand so high above *c n* as the barometric height measures, because there is air in the upper part of the tube, and no *vacuum* as in the barometer.

If we press down the tube until it reaches further and further into the mercury of the wide tube, the volume of the enclosed air will become smaller. We now press the tube so far down that the mercury in the tube stands exactly at the height of the level of the mercury *c n*. In this case the enclosed air is submitted exactly to the pressure of one atmosphere.

The height of the enclosed column of air exposed to the pressure of one atmosphere is now measured: it amounts to five centimetres.

If we again draw up the tube the volume of air increases, but at the same time the top of the mercury rises above the level *c n*. Provided we draw the tube so far up that the enclosed air occupies a length of ten centimetres in the tube, the height of the top of

the mercury above the level *c n* will be exactly half of the height of the barometer observed at the moment. For instance, if the barometer stand at 760 millimetres, the top of the mercury will be exactly 380 millimetres above *c n*.

The half of the atmospheric pressure is, therefore, counterbalanced by the column of mercury under the enclosed air, and the pressure which the latter has to sustain is only equal to the pressure of half the atmosphere; its volume, however, is twice as large as it was when supporting the pressure of one atmosphere. If, now, we raise the tube so far that the enclosed air occupies a length of fifteen centimetres, so that its volume is three times greater than it was, the height of the column of mercury in the tube amounts to two thirds of the barometric height: the enclosed air has, therefore, only a pressure of one third of an atmosphere to sustain.

Measurement of heights by the Barometer.—If the air were not an elastic fluid, but were like water, it would be extremely easy to compute heights by the barometer. At the level of the sea, the barometer stands at 760^{mm}, as soon as we ascend 11,5 metres, the barometer falls to 759^{mm}; a column of air of 11,5 metres in height will, therefore, equipoise a column of mercury of 1^{mm} in height.

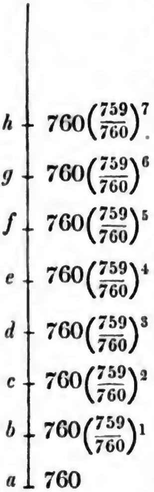
From this we may calculate the density of the air, for it is to that of mercury as 1^{mm} is to $11,5^{m}$ or as 1 to 11500, that is the density of the air is $\frac{1}{11500}$th of that of mercury. The density of the air, is, therefore, $\frac{13,6}{11500}$, or nearly 0,0012 that of water, since water is 13,6 times lighter than mercury. If now the air were like water, the density of the strata of air lying above us would be equally great, and we should then only have to ascend 11,5 metres to have the barometer again to fall 1^{mm}; and if by continued ascent, the barometer had fallen *n* millimetres, we should then have attained a height $n \times 11,5$ metres. But the air is elastic, the smaller the pressure weighing upon it, the less will be its density; consequently the higher we ascend, the more rarefied is the air.

The law by which the density of the air diminishes by constant ascent, and the relations existing between the height of the barometer and elevations above the soil can be developed by *Mariotte's law.*

Suppose the barometer to stand at 760^{mm} at any given spot. If we ascend 11,5 metres, the barometer will fall to 759^{mm}, or

what is the same thing $760\frac{759}{760}$. Without any serious error, we may assume that the whole layer of air every where at a height of 11,5 metre, is of equal density with that at the level of the sea. In Fig. 105, *a* is a point on the earth's surface, *b* is a point lying $11{,}5^m$ higher, and each one of the several points *c*, *d*, *e*, &c., is $11{,}5^m$ above the lower one. As the density of the air is proportionate to its pressure, the layer *b c* is less dense than the layer *a b*, and the densities of these layers will be as the height of the barometer at *a* and *b*, that is the density of the layer *b c* is $\frac{759}{760}$ of the density of the layer *a b*.

FIG. 105.



If now we ascend from *b* to *c*, the barometer does not fall so much as 1^{mm}, but only $\frac{759^{mm}}{760}$. The height at which the barometer stands, is, therefore, $760\frac{759^{mm}}{760} - \frac{759}{760} = \frac{759^2}{760} = 760\left(\frac{759}{760}\right)^2$. In this manner we may further conclude that the densities of the layers *b c* and *c d* are as the heights of the barometer *b* and *c*, and that consequently the layer *c d* is $\frac{759}{760}$ times lighter than the layer *b c*. If, therefore, the layer *b c* could support a column of mercury of $\frac{759^{mm}}{760}$, the layer *c d* can only bear a column of $\frac{759}{760} \times \frac{759}{760} = \left(\frac{759}{760}\right)^2$ millimetres; and if we rise from *c* to *d*, the barometer must fall $\left(\frac{759}{760}\right)^2$ millimetres. At *d*, likewise, the height of the barometer is $760\left(\frac{759}{760}\right)^2 - \left(\frac{759}{760}\right)^2 = 760\left(\frac{759}{760}\right)^3$.

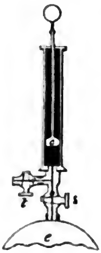
It will easily be understood that formulæ may be constructed from these considerations by the aid of which the difference of height of two places may be computed, if the height of the barometer be accurately measured at both places.

The Air Pump must be ranked amongst the most indispensable and important instruments of the Natural Philosopher, and has

undergone many alterations and improvements since its invention by *Otto von Guericke*. We will now consider it in its most simple form, in the small air pumps which are at present used in all chemical laboratories.

We must suppose a hollow cylinder, perfectly closed below, and having a piston *c* closely fitting to the bottom. If now the piston be forcibly drawn up, a *vacuum* is formed below it, provided the friction be air tight against the sides of the cylinder. Nothing, however, can be done by means of this *vacuum* since we can neither see into it nor put anything within. But if a canal lead from the lower part of the cylinder into a sphere, a balloon *e*, for instance, which although filled with air is fully closed against the external atmosphere, a portion of the air in *e* will enter the cylinder, owing to its elasticity, on lifting up the piston, and a rarefaction of the air in *e* will consequently follow. In order, however, that the air may not return into *e* on the descent of the piston, a cock *s* is attached by means of which the communication between *e* and the cylinder may be interrupted, or again restored at will. This cock *s* is closed as soon as the piston comes over it. If we now press down the piston, the air in the cylinder will only be compressed, if we afford it no means of escape; this, however, it will have, if we open a second cock *t*. When the piston is at the bottom, *t* is again closed, and *s* opened, while another drawing up of the piston produces another rarefaction in *e*. By frequent repetition of this operation, we may obtain a considerable rarefaction at *e*.

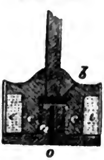
FIG. 106.



The apparatus in this form is, however, inconvenient on many accounts. In the first place, the continual opening and shutting of the two cocks is extremely troublesome. But for the cock *t* we may substitute a valve which closes on the elevation, and opens on the depression of the piston. The lower part of the piston consists of a brass plate with a screw screwed into a piece of brass *c c*. The screw is perforated along its length, and a piece of silk *r* bound over the opening *o*. In the piece of brass to which the screw is fixed, there is an opening *b*. On the elevation of the piston, the air in the upper part of

FIG. 107.

FIG. 108.



the cylinder forces itself through the opening *b* in the silk, and presses it tightly upon the opening *o*; the piston acts, therefore, on rising exactly as if it were solid: the air passes from the space *e* through the open cock *s* into the lower part of the cylinder; but if after the cock *s* is closed, the piston be again pressed down, the air in the under part of the cylinder will be compressed, and raising the valve *r*, will escape through the opening *b* into the upper part of the cylinder.

The piece of brass *c* is inserted into a cork bound round with fine leather. This leather is pressed against the sides of the cylinder by the elasticity of the cork.

The cock *s* may also be dispensed with, if a second valve be applied to the part where the canal opens into the cylinder. This valve opens on drawing up the piston, and closes with its descent. The accompanying figure shows a very useful little air pump, one third of the natural size. It has been constructed in accordance with the plan of Gay Lussac. The canal goes vertically down from the lower end of the cylinder into a canal *a b* running horizontally. The cork at *d* should be closed, and the receiver from which the air is to be exhausted, screwed on at *a*; then on raising the piston, a portion of the air will pass first through the horizontal, and then through the vertical canal into the cylinder, and on pressing down the piston, will escape through its valve. To admit the air again into the receiver, nothing more is necessary than to open the cock at *d*.

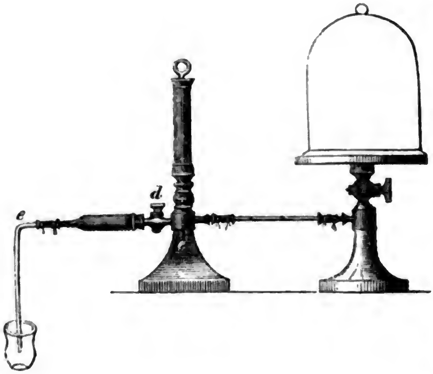
FIG. 109.

By means of the screw *f*, the air pump may be screwed on to a table, or to a board secured to a table, and will thus remain fixed while being used.

We designate by the term *receiver*, the space from which the air is to be exhausted. The best form for receivers of air pumps, designed for general experiments, is a bell made of glass, the under and somewhat broader edge of which must be made perfectly smooth and polished, so that it may fit into a smoothly cut plate with such exactitude as to prevent the

entrance of any air between the two. A perfect exclusion can, however, only be effected by rubbing the edge of the bell with tallow before placing it upon the plate. In Fig. 110 we see a receiver of this kind in conjunction with a little air pump. From the middle of the plate, a canal goes vertically down and then passes further on through a short horizontal tube. At the end of this short horizontal piece of tube, a glass tube is attached by means of an india-rubber tube, and is secured in a similar manner to the air pump on the opposite side. The degree of rarefaction that can be obtained by pumping, may be measured by what is termed the barometric test. This is applied to the smaller air pumps in the manner shown at Fig. 110. A glass tube of about thirty inches in length is immersed at its lower end into a vessel full of mercury.

FIG. 110.



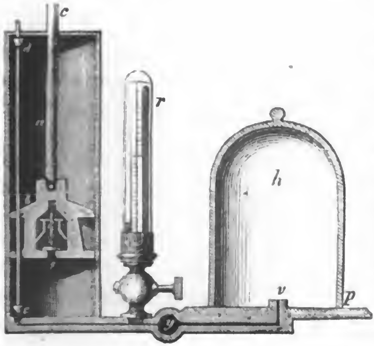
Above it is curved, and secured to the pump by means of a short but wider piece of tube. If the cock *d* be opened, the mercury will ascend in the tube in proportion as the rarefaction is continued. If it were possible to create a perfect *vacuum* by means of the air pump, the column of mercury raised in the tube *e*, would be equal to the height of the barometer.

With a well constructed apparatus of this kind, we may make most of the experiments of the air pump, with the exception perhaps of some few, requiring very large receivers, or a very rapid and complete exhaustion. On this account, air pumps of this kind are to be recommended for all popular institutions, not possessing the funds necessary to obtain the most highly finished apparatus, viz. when they are made four, five, or six times larger than the one represented in Fig. 109.

Larger air pumps of various forms have been constructed, but all are based upon the same principles as the ones above described. We will consider more attentively one of the best arranged of these apparatus.

In a cylinder *a* which must be perfectly well finished, the piston *b* moves by means of the rod *c*, which must be perfectly air-tight, no air being able to escape between the piston and the cylinder.

FIG. 111.



In the piston there is a valve *s*, which must move easily and open upwards. It rises when the pressure from below is greater than from above, but otherwise remains hermetically closed.

The rod *e d* is the valve for the cylinder. If the piston be raised, the whole rod is lifted up, but *d* soon strikes the upper plate of the cylinder, and the piston moves with some friction along the whole rod. As soon as the piston descends, the truncated cone *e* is pressed into the conical opening below it, so that the upper surface of the cone *e*, and the bottom of the cylinder form a plane surface, and the piston may, therefore, rest perfectly on this bottom.

From the above mentioned conical opening, a canal goes on to *v*. Here there is a screw, to which may be attached the balloons or receivers that are to be exhausted.

The screw *v* is in the middle of a plate *p*, on which the bell *h* may be placed. Let us assume that the piston is on the lower plate of the cylinder. If then it be raised, a *vacuum* will be formed, provided all the valves remain shut; but the valve *e* is opened, and the air from the bell passes partly over to the cylinder.

But by this means, the air in the bell and in the canal of the bell is rarefied, consequently the valve *s* in the piston must remain closed. On the descent of the piston the valve at *e* is shut, and all passage closed for the return of the air from the cylinder into the bell. The air thus shut in will escape through the valve

s, until the piston reaches the bottom of the cylinder. Another upward stroke of the piston produces a fresh rarefaction in the bell.

We may easily understand that an absolute vacuum can never be produced in this manner below the bell, however long we may continue the above mentioned operation, because by every fresh stroke of the piston, the air below the bell is only re-rarified; we may, however, easily manage to reduce the air until it has only a tension of two millimetres. The time required to produce a certain degree of rarefaction will be shorter or longer according to whether the volume of the receiver be small or large in comparison with the volume of the cylinder.

If we have exhausted the pump sufficiently, the atmospheric pressure acting upon the piston is not counterpoised by any opposite pressure within. In order to raise the piston, we must apply a force of 1033 kilog. for every square centimetre of its surface, besides having to overcome the friction.

In air pumps with two cylinders, the pressure on the one piston acts against that weighing down the other piston, and thus nothing but friction remains to be overcome.

In the canal connecting the receiver with the sucker, a double-acting cock *y* is applied; that is to say, a cock having two openings, a common straight aperture connecting the receiver with the sucker, while the pump is being worked, and a lateral opening closed by a metal stopper *b*, and turned towards the sucker, when the receiver is to be shut off. If we wish to let air again into the receiver, we must turn the cock in such a manner, that the lateral opening is turned to the receiver, and then draw out the metal stopper.

FIG. 112.

FIG. 113.

In these air pumps, the barometric gauge is generally differently constructed from the above mentioned. It is usually a shortened barometer, closed in a long narrow bell *r*, Fig. 111, and connected with the canal of the machine. This connection may be cut off, or again restored by means of a cock. Fig. 113 represents an isolated barometer gauge, seven inches in length. The mercury entirely fills the closed leg, and only begins to sink, when the pressure of air acting on the open leg is reduced to one fourth of the atmospheric pressure. If this degree of rarefaction be obtained, the barometric test will

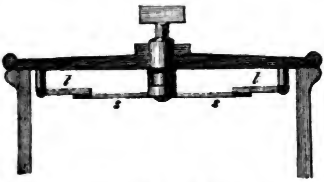
always give the pressure of the air in the receiver, which is equal to the difference of the height of the two columns of mercury. As soon as air is again admitted, its pressure will drive the mercury forcibly back into the closed tube; we must, therefore, moderate the rush of air to prevent the top of the glass tube from being broken through.

Otto von Guericke made by means of the machine which he constructed, the remarkable experiment with the *Magdeburg Hemispheres,* which consisted in producing a *vacuum* in a hollow metal ball, the halves of which were only simply laid on each other. Before the vacuum is formed, it is easy to separate the parts, but when they have been entirely exhausted of air, and there is nothing to counteract the external atmospheric pressure, they adhere most extraordinarily close together. If, for instance, the radius of the ball were only 1 decimetre, a section through its centre would be 314 square centimetres, and consequently the external pressure holding the two halves together would be more than 314 kilogrammes. In order to make the contact more perfect, the edges of the hemispheres are rubbed with fat, like the bell before it is placed on the plate; the cock *c* which is open while the pumping goes on, is closed before the united hemispheres are taken off the air pump, and the re-entrance of air is thus prevented.

FIG. 114.

The air pump is used in many experiments. By this means it may be shown that burning bodies are extinguished in a vacuum, that smoke falls to the ground like a heavy body; that air, as it were, is dissolved in water; that a layer of air intervenes between fluids and the sides of the vessels in which they are contained, for its presence is manifested by a number of little globules that increase in proportion as the air diminishes. By the aid of an air pump, we may cause cold water to boil.

FIG. 115.

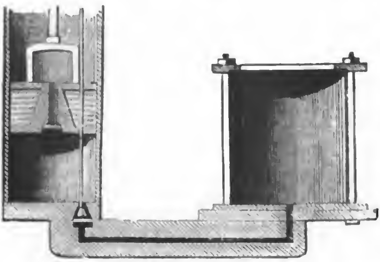


A glass cylinder about one metre in height, and having a diameter of about twelve centimetres, whose upper and lower edges are carefully smoothed, is placed upon the plate of the air pump; the upper aperture of the cylinder is closed by a metal plate (as exhibited in Fig. 115) hermetically attached to

the polished glass edge by being rubbed with fat. Through the middle of this plate, there passes an air-tight metal cone, (almost like a cock) that may be turned at will. Two horizontally secured rods *s* revolve with this metal cone.

On each of the rods, there is a little metal plate *t* fastened to a rod projecting from the metal plate by means of a horizontal pin, round which it must revolve easily. When the rod *s* is turned so far from the position indicated in the diagram, that the little plates *t* are no longer supported, the latter will turn round throwing off whatever may have been laid upon them. It is better that the two plates *t* should not turn round simultaneously. We lay then a piece of metal, and a little feather on each plate; and if we let the one plate turn over before we have done pumping, the piece of metal will fall much faster than the feather. But when the air is quite exhausted, and the second plate is turned over, the feather will fall as rapidly as the piece of metal.

FIG. 116.



The condensing Pump serves to condense the air. It differs essentially from the air pump, in having valves that open and shut in opposite directions, as exhibited in Fig. 116. When the piston descends, it compresses the air, driving it into a receiver; when it ascends, the external air opens the valve of the piston, and presses into the cylinder, while the compressed air in the receiver keeps the bottom valve of the cylinder shut. Another depression of the piston reopens the bottom valve, and closes the piston valve, when a new supply of air is forced into the receiver, &c.

The barometer gauge of the condensing machine is a straight tube, closed at the top and filled with air, having its lower open end plunged in a vessel of mercury. On beginning the experiment, the air into the tube is below the pressure of one atmosphere, if the levels of the mercury in the tube and the vessel are of equal weight.

The more the pressure increases, the higher the mercury rises in the tube. From the height of this column of mercury, and the

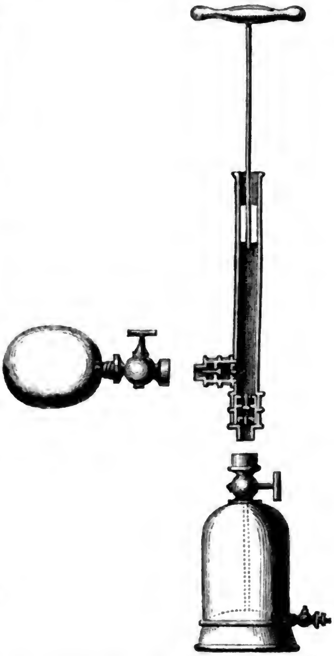
compression of the air in the tube, it is easy to determine the degree of condensation in the receiver.

In this machine, the receiver must be screwed tightly on the plate to prevent its being raised by the compressed air.

Condensing pumps have been so contrived as to screw on the apparatus in which air is to be compressed. They have only one cylinder, and one piston without a valve. On the one end of the cylinder, the reservoir is screwed on, in which the air is to be compressed; on this there is a valve, through which air may enter, but cannot escape from the reservoir. In order to admit fresh air into the cylinder, after a portion has been compressed into the reservoir, the cylinder has either a lateral aperture as in Fig. 117, or a lateral valve like Fig. 118. The latter is particularly applicable when we want to compress a special gas, for it is then only necessary to put the glass reservoir in connection with the tube of the lateral valve.

FIG. 117.

FIG. 118.



The first of these condensing pumps is mainly used for loading air guns, the construction of which will be made clear by the accompanying figures. When by help of the condensing pump, we have compressed the air in the piston of the air gun to the density of 8 or 10 atmospheres, a barrel is screwed on, along which the ball is directed. If the valve closing the piston be

FIG. 119.

FIG. 120.

FIG. 121.

opened by the trigger, a part of the enclosed air will escape with great violence, carrying the ball with it; but the valve closes immediately. A good air gun may give as much speed to a ball as a musket can do. Many shots may be discharged without reloading, the number being in proportion to the size of the piston.

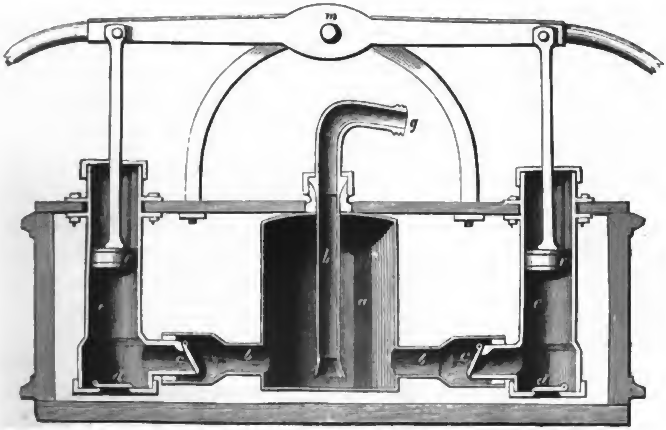
Hero's Ball.—We can also force fluids out of vessels with great violence by means of compressed air, as is the case with *Hero's Ball.* A tube passes nearly to the bottom, through the neck of a vessel partially filled with water. The tube terminates above in a point with a fine aperture. If the air in the upper part of the vessel have in any way been compressed, the pressure, which it exerts on the surface of the water, will drive the fluid out of the fine aperture after the manner of a fountain. We may make use of a flask, closed by a cork, through which passes a glass rod drawn out to a fine point. If the glass rod does not penetrate far into the vessel, we obtain, by this arrangement, the dropping bottle with which chemists commonly wash their precipitates. The air in this may be compressed by blowing with the mouth through the tube. If the air enclosed in the apparatus be of equal density with the surrounding atmosphere, and we place it under the bell of the air pump, it will begin to burst as soon as we have exhausted the air. This apparatus is often constructed in large dimensions entirely of metal. In that case, the neck is furnished with a cock *r*, above which the thin tube may be screwed on. The air is compressed by means of a con-

FIG. 122.

densing pump screwed on in the place of the pointed tube. When the vessel is charged, we close the cock, remove the pump, and screw on the pointed tube. As soon as the cock is opened, the water rushes out to the height of from 30 to 100 feet, if the air has been compressed to 2, or from 5 to 6 atmospheres.

The Fire Engine.—Fig. 123 represents the combination of the forcing pump with Hero's Ball; the cylinders, of which we will

FIG. 123.



consider the one to the right hand, stand in a trough filled with water. If the piston *f* be raised, the valve *d* rises, and the water presses into the cylinder *e*. On the descent of the piston, the valve *d* closes, the valve *c* is opened, and the water is forced through the narrow tube *b*, into the air chamber *a*. This air chamber is nothing more than a large Hero's Ball, and the more water is pumped into it, the more is the air in its upper part compressed. The tube *h* reaches almost to the bottom of the air chamber; at *g* a tube with a narrow opening is screwed on. A strong jet of water is driven from the aperture by the pressure constantly exercised upon the water by the air compressed in the chamber. A leather pipe, with a metal spout, may be screwed to an opening in the side of the air chamber near the bottom: this pipe also throws out a jet of water which can be more easily directed, and brought nearer to the burning parts than the stream from the aperture *g*. The raising and lowering of the piston is managed by a lever, whose fulcrum is *m*. Both rods of the pistons are so

attached to this lever, that the one ascends as the other descends, and a fresh supply of water may, therefore, be uninterruptedly conveyed to the air chamber.

FIG. 124.

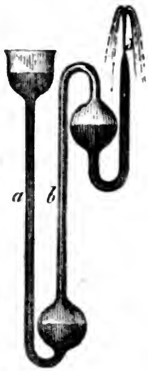
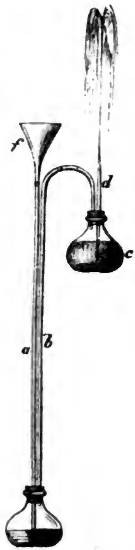


FIG. 125.



Hero's Fountain. — The most simple mode of constructing Hero's Fountain by means of glass tubes, and a glass blower's lamp is shown in Fig. 124. The column of water in the tube *a* compresses the air in *b*; the compressed air presses upon the surface of the water in *c*, and consequently the water must gush out at *d*. According to the same principle, Hero's Fountain in Fig. 125 is composed of glass tubes, glass flasks, and a funnel. It is evident that the vessel *c* must be supported in some way. When the apparatus is set into action, the vessel *c* is filled with water, and its neck closed with a cork, through which pass the tubes *b* and *d*. Water is then poured into the funnel *f*, on which the water begins to gush from the tube *d*.

FIG. 126.

Measurement of the pressure of Gases.—There are two means by which we may measure the pressure of gases, viz. by columns of liquids, and by valves. An apparatus designed for this purpose is termed a *manometer*. The barometer gauge upon the air pump, and the condensing machine are *manometers*.

Safety tubes belong in some respects to *manometers*, for they measure the pressure of the gas in the apparatus to which they are attached. If their tension be equal to the atmospheric pressure, the fluid will stand at the same level in both limbs, (Fig. 126); if this be not the case, the pressure may be determined in the interior of the enclosed space by the

difference of the columns of liquid in the two limbs, provided the density of the liquid in the safety tube be known. These safety tubes were invented by *Welter,* and are of the greatest utility in many chemical operations, by preventing explosions as well as the forcing back of enclosed liquids by the air's pressure when absorption takes place.

In Figs. 127 and 128 there are two loaded or safety valves represented. If the weight be known that will load such a valve, and the size of the surface of the valve which has to support the vertical pressure of the gas, the tension of the gas at the moment when it is able to raise the valve may be calculated. For instance, if the loading of the valve be 100 kilog., and the area of the value 25 square centimetres, each square centimetre of this area will have to bear 4 kilogrammes. As now the pressure of the atmosphere upon each square centimetre amounts to 1,0325, the tension of the gas able to lift this valve will be equal to $\frac{4}{1,0325} = 3,87$ atmospheres, to which must be added one atmosphere more on account of the pressure of the air, borne by the valve besides its other load. This apparatus is applied to liquids as well as gases, and by its means, the boilers, tubes of communication, and the cylinders of the steam engine are proved.

FIG. 127.

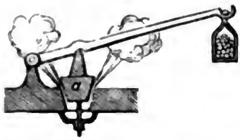


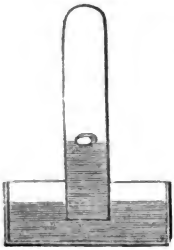
FIG. 128.

CHAPTER VI.

ATTRACTION BETWEEN GASEOUS AND SOLID, AS WELL AS BETWEEN GASEOUS AND LIQUID BODIES.

THE following experiments prove most evidently that a considerable attraction exists between the particles of solid and gaseous bodies. If we place a piece of glowing charcoal under mercury, and then let it ascend into a cylinder, whose upper part is filled with carbonic acid, shut off by means of the mercury from any communication with the external air, and whose volume is about 20 times greater than that of the charcoal, the carbonic acid will in a few minutes be so condensed by the charcoal, that the mercury will rise to the top of the cylinder. The whole mass of the carbonic acid, which before filled all the upper part of the cylinder is now condensed by the attraction existing between the gas and the pores of the charcoal, the former having been *absorbed*. A similar experiment succeeds with many other gases. If the charcoal have lain any length of time in the air, the experiment does not prove quite successful, as we may easily understand, if we reflect that it absorbs atmospheric air, and the vapour distributed through the air, and that its capacity for absorbing other gases is consequently diminished.

FIG. 129.



If charcoal that has absorbed gas be brought under the air pump, or kindled, it will liberate the absorbed gas.

Absorption of gases is at all times accompanied by a development of heat, which is more considerable in proportion to the amount of absorption.

In the manufacture of gunpowder, the charcoal is triturated to a very fine powder, which absorbs atmospheric air with such

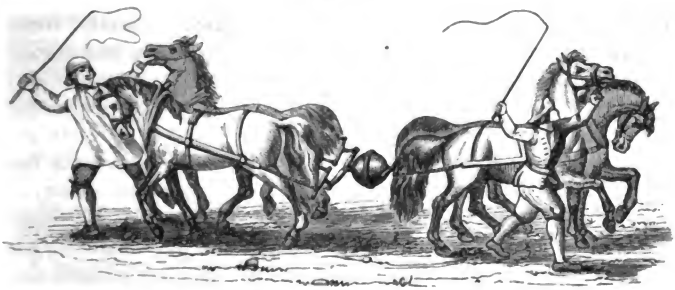
avidity that a considerable degree of heat takes place in the mass and frequently gives rise to combustion.

If a fine jet of hydrogen gas be thrown upon spongy platinum, absorption of the gas follows with such violence as to make the platinum red hot and inflame the hydrogen gas. On this principle Döbereiner's lamp is constructed.

Absorption is considerably promoted when the solid body is in a finely divided condition, as is the case with charcoal powder and spongy platinum, because of the increased number of points of contact between the solid bodies and the gas, but this finely porous condition is not indispensable to effect a condensation of the gas, it also occurs if the solid body has a perfectly smooth, or metallic surface; in this case, however, the condensation is less considerable. If we put a piece of platinum, having a perfectly smooth metallic surface, into a mixture of oxygen and hydrogen, both gases will be so much condensed as gradually to combine and form water.

Not only platinum and charcoal, but all solid bodies exhibit in a greater or less degree this remarkable relation to gases. Every solid body is as it were surrounded by the condensed atmosphere of some gas, which it is often very difficult to separate from it, and which, even if its surface be perfectly freed from it, will again adhere after a time, if the body come into contact with gases. Thus for example, glass is always surrounded by a coating of condensed air, which in the construction of barometers can only be removed by the boiling of the mercury in the tube. If water be poured into a glass flask, and placed over the fire, there is

FIG. 130.



soon seen a number of bubbles forming on the bottom long before the water boils. This is owing to the layer of air, which from

its great condensation was before imperceptible, but now forms bubbles after its expansion by heat. Similar bubbles appear if the vessel with water be placed under the receiver of the air pump, and then exhausted.

Such gaseous bodies as easily pass over into a fluid condition (vapour) are rendered liquid by their attraction for solid bodies. Thus chloride of calcium attracts the vapour of water with great rapidity, condenses it to water, and at length dissolves in the water. Common salt also attracts the vapour of water from the air, and becomes moist. It is the same with potash and many other bodies.

Bodies that attract the vapour of water from the air are called *hygroscopic* bodies; to these belong, besides those we have mentioned, wood, hair, whalebone, &c.

Absorption of gases by liquids.—Liquids exhibit a similar relation to gases as that we have just considered in solid bodies. This may be made evident by so far altering the experiment given in Fig. 129, as to substitute ammoniacal gas for carbonic acid, and water for charcoal. The ammoniacal gas is so eagerly absorbed by the water, that all the gas disappears at once, and the tube becomes filled with water.

The water absorbs 700 times its volume of ammoniacal gas, and 500 times its volume of muriatic acid gas. The power of absorption of liquids depends upon the temperature and degree of pressure. Liquids absorb larger quantities of gas at a low temperature, and under strong pressure, than a high temperature and under less pressure.

Water almost always contains a tolerably large quantity of absorbed air, from which it can only be freed by prolonged boiling. Carbonic acid, amongst other gases is pretty freely absorbed by water, as for instance, beer, champagne, and certain mineral waters.

SECTION III.

OF MOTION AND ACCELERATING FORCES.

CHAPTER I.

DIFFERENT KINDS OF MOTION.

Rest and Motion.—A body that changes its position with respect to another is in *motion;* it is at rest if no such change occur. Every form of rest or motion observed by us is only relative, not absolute. The trees are at rest in relation to the neighbouring hills; trees have an unchangeable position on the earth's surface; but trees and hills are not on that account in a state of absolute rest; they with the whole earth on which they stand traverse the vast orbit of our planet. Although we know that we fly through the space of heaven with the earth, as it revolves round the sun, we cannot say anything definite respecting our own absolute motion, as we know not whether the sun is an immoveable centre of the world. Everything, however, seems to imply that the sun itself is only a planet revolving round another sun, which in its turn is not fixed; but we are not able to determine or even to conjecture what the centre of all motion is.

There are two essential points regarding motion that we must consider, viz. *direction* and *velocity.* If a body move continually in one direction, its course is in a straight line; but if the direction of its motion constantly change, its motion is curvelinear. If we draw a tangent to the curve at a point of the curve occupied by the body at any given instant, this tangent will show the direction of the motion of the body at that moment.

Uniform motion.—A body has an uniform motion if it pass over equal spaces in equal times. If a body moving in a straight line, advance equally far, sixty feet for instance, in

each minute, thirty feet in every half minute, and one foot in every second, it moves uniformly. As the spaces traversed in equal times are equal, it follows that the relation between time and space remains constant. This relation we term the *velocity* of uniform motion. If we take double or triple the time, the space traversed will be doubled and tripled; and the relation consequently remains the same. The number expressing the velocity depends upon the units chosen for space and time. If we were only to express the velocity by a number, without giving the units employed, the velocity would then be wholly undefined. The simplest mode of expressing velocity is by giving the space traversed by the body in an unit of time, as a minute or a second. Thus for instance a man walks as a general rule with the velocity of 2.5 feet in a second. An ordinary wind has a velocity of 60 metres in the minute; a hurricane 2700 metres in a minute. These two last named velocities admit of comparison, as they are expressed in the same units; thus the velocity of the hurricane is 45 times as great as that of an ordinary wind. If we would compare the speed of a man with the velocity of the hurricane, we must first reduce both to a like unit. As matter is inert, a body once having an uniform motion would continue to move in the same direction, and with the same velocity, unless a second force were to act upon it, changing its direction alone, or its velocity alone, or both; for by itself a body can change nothing in this respect, either with regard to its conditions of rest or motion. Thus we are to understand the law of inertia, and not as the older philosophers, who maintained, that matter had a prevailing tendency to rest. If we see that the motion of a body be in any way changed, if for instance, its velocity increases or diminishes, its motion ceases, or changes its direction, then must this change always be occasioned by some external cause. A stone thrown towards the sun would continue its course till it reached the sun, were it not prevented by the resistance of the air, and by the force of gravity drawing it back to the earth.

Accelerated and retarded motion.—A constant change of velocity can only be effected by a constantly acting force, termed *accelerating* or *retarding* according as it augments or diminishes motion. If at any moment of the varying motion, all the accelerating or retarding forces were to cease to act, the motion would become uniform from that moment. The velocity of a varying motion in a given moment is determined by computing how far the body would

move in the unit of time, if all acceleration and retardation were to cease from the said moment.

A motion is termed *uniformly accelerated* or *uniformly retarded,* if the velocity increase or diminish equally in equal times. Such motions are produced by forces acting continually with the same intensity as is the case with gravity. A heavy body falls with an uniformly accelerated velocity. If we set out with the supposition that the intensity of gravity is the same at the different places traversed by the falling body, (and experience justifies us in this assumption at least within certain limitations), all laws of freely falling bodies may be developed by a simple mode of reasoning.

As gravity acts in the same manner at every moment of a fall, the velocity of the falling body must also increase equally, on equal terms, that is the motion must be a uniformly accelerated one. If the falling body attain, in the first second of its descent, a velocity g, it must after 2, 3, 4 . . . t seconds have attained to a velocity of $2\,g$, $3\,g$, $4\,g$ . . . $t\,.\,g$; which may be thus generally expressed in words: *the velocity of a freely falling body is always proportionate to the time elapsed during its fall:* or it is

$$v = g\,.\,t$$

if v represent the velocity acquired by the body during its fall of t seconds, and g its velocity at the end of the first second.

What space will, therefore, the body fall through in 1, 2, 3, 4 . . . . t seconds? At the beginning of the first second, its velocity is equal to o; at the end of the same, it is g. As now the velocity increases uniformly, the space fallen through in one second must clearly be the same as if the body were during one second moved by a velocity ranging half way between the beginning and ending velocity: that is between o and g. But this medium velocity is $\frac{1}{2}\,g$, and a body falling during one second with a velocity of $\frac{1}{2}\,g$, passes over a space $\frac{1}{2}\,g$.

In the same manner, we may find by deduction the space passed through by a body falling during two seconds. The starting velocity is o; the closing velocity $2\,g$; the medium velocity is consequently $\frac{2\,g}{2}$ and a body moving during two seconds with this velocity, passes through a space equal to $2.2\,\frac{g}{2}$.

In three seconds the body passes through a space equal to $3.3\,\frac{g}{2}$ for

the starting velocity is o, the closing velocity $3\,g$, and the medium velocity is consequently equal to $3\,\frac{g}{2}$; and a body must move uniformly with this velocity during three seconds, if it traverse the same space through which a heavy body will fall in the same time. We will express this generally. If a body fall during t seconds, it must traverse a space equal to what it would have done during the same time with an uniform motion, if its velocity were a medium between o and $g\,.\,t$, that is $\frac{g}{2}\,.\,t$. But a body moving t seconds with a velocity equal to $\frac{g}{2}\,t$ traverses a space

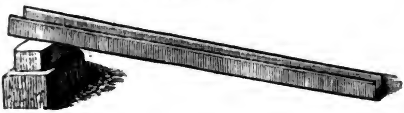
$$s = \frac{g}{2}\,.\,t^2$$

or expressed verbally: *the spaces described are proportional to the squares of the times.*

Experiment, however, can alone prove whether these premises be correct, and whether gravity actually be an uniformly accelerating force. This question cannot be directly solved, since the velocity with which bodies fall augments so rapidly, that after the first few moments it becomes impossible to determine accurately the spaces passed through in given times. But although we cannot find this by direct experiment, we may arrive at the result by indirect means. The most simple method is *Galileo's inclined plane,* but the one possessed of the greatest degree of accuracy is *Atwood's falling machine.*

Galileo's inclined Plane.—Galileo studied the laws of descent by rolling easily moving bodies down an inclined plane. To follow his experiments, it is best to make use of a canal of wood, about 10 or 12 feet in length (Fig. 131) polished as smoothly as possible in the interior, and divided into feet and inches. The canal must be inclined by being supported at one end. If it were placed perfectly horizontally, a ball laid upon it would remain at rest, owing to its gravity being entirely counterpoised by the resistance of its horizontal support. If the canal were placed vertically, the ball would fall freely with the whole force of its gravity; but

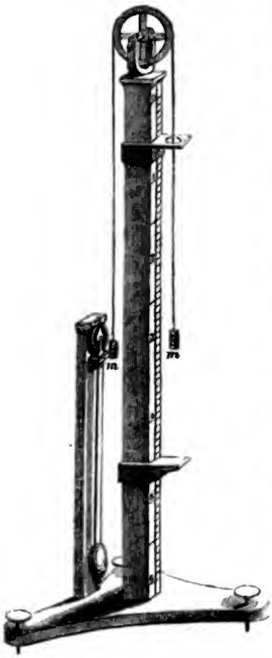
FIG. 131.



if the body be inclined, the force of gravity will be diminished in a certain fixed relation. It follows from the principles of statics, that we obtain the amount of accelerating force urging the ball down the inclined plane, if we multiply the accelerating force of gravity with the sine of the angle of inclination of the plane. Whatever may be the relation in which a force is diminished, whether it be reduced to the half, the third, or the fourth part of its original amount, the absolute amount of the motion produced will alone be changed, while the relations of the spaces traversed in given times will remain the same. The laws derived from experiments with the inclined plane, are therefore the true laws of gravity. If we slip a ball at a definite moment from the upper end of the canal, and note the spaces traversed in 1, 2, 3, seconds, we shall find that the spaces are as the squares of the time necessary to traverse those spaces. Gravity is, therefore, really an uniformly accelerating force.

Atwood's Falling Machine consists essentially of a pulley revolving round a horizontal axis, and fastened to the top of a vertical column, about 7 feet in height (Fig. 132). A string is slung over the pulley having equal weights m at its extremities. If we attach an extra weight n on the one side, equilibrium will be disturbed; the weights m and n will sink on one side, and the weight m on the other will be raised up. The velocity with which this takes place is much less considerable than in a free fall, because the moving force, the force of gravity of the extra weight n, has not only to set in motion the mass m, but also the mass $2m+n$.

FIG. 132.



If, for example, each of the weights m were 7 oz. but n 1 oz. only, the extra weight of 1 oz. would have to put a mass of 15 oz. in motion; the motion will follow the same laws, as in a free fall, with this difference only, that the intensity of the accelerating force is here 15 times smaller.

If, therefore, a freely falling body, traverse 15 feet of space during the first second, the space traversed in this case, in the first second, will be only 1 foot.

It is easy to see that the motion will be slower, the smaller the extra weight *n* is in relation to *m;* and we may, therefore, by proper alterations in *n*, make the motion as slow as we chose.

The vertical column has been divided into feet, for the greater convenience of measuring the spaces of falling. The upper point is the zero of the scale. Two slides, one of which is perforated can be secured to any part of the scale.

It is necessary to know thus much of the apparatus in order to understand the experiments. In the first place, it is easy to prove, by means of this machine, that the space is as the square of the time of falling. Let *n* be so chosen that the descent in the first second is 1 inch. If the lower end of the weight *m*, carrying the extra weight be at the zero point of the scale, the weight will be at the first mark below zero, in the course of one second from the time of the commencement of motion.

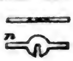
If the space traversed during the first second of falling be 1 inch, it must be 4 inches during the two first seconds; if, therefore, we move the slide to 4 inches below zero, the weight that began its motion at the point zero, will strike at the end of two seconds.

If we let the motion always begin from the same point of the scale, viz. from zero, the slide must be fixed at 9, 16, 25, 36, 49, 64 inches below that point, if the weight is to strike in 3, 4, 5, 6, 7, 8 seconds. This experiment fully confirms the law, that the spaces traversed in falling are as the squares of the time of falling.

We have shown above that this law follows from the assumption that the velocity is proportionate to the time of falling. The truth of the inference proves also indirectly the correctness of the assumption. The relation existing between the time of falling, and the velocity of the body at any given moment cannot be directly ascertained either in a free descent, or by means of the inclined plane, since in order to obtain this result, it would be necessary that the velocity of the body should not increase from that moment, consequently we must be able suddenly to destroy the action of gravity on the body. By means of the falling-machine, we may arrest the accelerating force at any moment. The accelerating force is only the gravity of the extra weight *n*;

if now we give to the excess of weight n, the form represented at Fig. 133, we may arrest it by means of the perforated slide at any moment, while the mass m continues to progress with uniform velocity from the time it ceased to be acted upon by an accelerating force. We may, therefore, by help of this contrivance determine directly the velocity at any one moment by the space traversed in the next second.

FIG. 133.



We have seen that if g be the velocity of the body at the end of the first second of falling, the space traversed in the same period of time will be $\frac{1}{2}g$. If now we have so arranged, that 1 inch is traversed in the first second, the closing velocity of the first second will be 2 inches, that is, if at the close of the first second the accelerating force cease to act, the body will traverse in the next second a space of 2 inches with uniform velocity.

It is easy to demonstrate that this relation actually exists between the time and velocity of falling. Let us, for instance, so place the weights $m+n$ before motion begins, that the under surface of n may stand at zero upon the scale; the perforated slide must also be so arranged that its upper surface stand at 1 inch, and the lower slide so that its upper surface may be as much below the mark, 3 inches, as the height of the weight m requires. If now we start the weights at a definite moment, the extra weight will strike in 1 second, and the weight m in 2 seconds. The upper point of the weight m has, therefore, traversed the space from zero to 1 with accelerated velocity in the first second, and has passed in the next second from 1 to 3 with an uniform degree of velocity.

That the velocity is really uniform after the removal of the extra weight, we see from this, that if without altering anything else we lower the slide 2, 4, 6, 8, or 10 inches; the contact occurs 1, 2, 3, 4, or 5 seconds later; consequently that a space of 2 inches is traversed in every succeeding second.

If we had so arranged the extra weight n that 2, 3, 4, 5, &c. inches were traversed in the first second, a space of 4, 6, 8, 10, &c., inches would be passed over, provided we removed the extra weight at the end of the first second.

We have assumed above that if the velocity be g at the end of the first second, the closing velocity in 2, 3, 4 seconds will be $2g$, $3g$, $4g$. Experiment fully confirms this. If we again assume, that the extra weight n be so arranged, that in the first second 1 inch will be traversed, and consequently in the next two seconds,

4 inches, there will be a space of 4 inches passed over in each succeeding second, provided we take off the extra weight at the close of two seconds; if we did not take off the extra weight before the close of the 3rd and 4th second, that is when a space of 9, or 16 inches had been passed over, the motion would continue from that time with an uniform velocity of 6 or 8 inches.

In a free fall the value of g may be taken at somewhat more than 30 feet. When we come to speak of the pendulum, we will give a more accurate estimate of its value. In a free fall, therefore, according to the above proved laws, the space passed over in the first second of falling must be about 15 Paris feet, while in 2, 3, or 4 seconds, it must amount to 60, 135, 240, &c.

Galileo himself made experiments regarding the free descent of bodies, which were subsequently repeated by *Riccioli* and *Grimaldi* from the Tower *Degli Asinelli* in Bologna; *Dechalles* has, however, made the most accurate experiments on the subject. The observed spaces through which bodies fall are always smaller than we might be led to expect from theory. This difference depends, however, solely upon the resistance of the air, which increases as the square of the velocity. In the *falling machine*, and the falling-canal, the resistance of the air does not influence the results.

It is frequently important to be able to compute directly the velocity corresponding to given heights of descent. A formula, according to which this calculation may be made, is obtained from the following equations $v = g, t$ and $s = \frac{g}{2} t^2$. By the elimination of t we find that

$$v = \sqrt{2 g s}.$$

The velocities are, therefore, as the square roots of the spaces. If for instance, a body had fallen from a height of 100 feet, its velocity would be, according to this formula, as follows: $v = \sqrt{2.30.100} = 77{,}4$ . . feet (without taking into account the resistance of the air).

When a body is projected by any force vertically upwards, it ascends with decreasing velocity; after a time its upward motion ceases, and it then begins to fall. The laws of this motion follow immediately from the foregoing. Suppose a body to be thrown upward with a velocity of 150 feet, it would ascend 150 feet in every second, provided gravity exercised no influence upon it. But as gravity imparts to a falling body in

1, 2, 3, 4, 5 seconds, a velocity of 30, 60, 90, 120, 150 feet, opposed to the direction of the upward motion, it is evident that the velocity of the ascending body is at the end of the 1st second $150 - 30 = 120$ feet; at the close of 2 seconds this velocity is $150 - 60 = 90$ feet; at the close of 3 seconds $150 - 90 = 60$ feet; in 4 seconds $150 - 120 = 30$ feet; and finally at the end of the 5th second $150 - 150 = 0$; and now consequently the body begins to fall. We have here an illustration of an uniformly retarded motion, for the velocity of the ascending body diminishes about the same in every second, viz. about 30 feet.

Let us put this in general terms. If n be the velocity at the beginning of the ascent, the velocity of the body will after t seconds be

$$v = n - g\,t.$$

The body ceases to ascend, when $n = g\,t$, that is, when the velocity acquired in falling during t seconds is equal to the velocity, with which the body began to ascend.

The time required by the body to reach the highest point of its course, is

$$t = \frac{n}{g}.$$

Let us now endeavour to ascertain the height attained by an ascending body in a given time. According to the above given illustration, the body would have attained a height of 150, 300, 450, &c., feet, 1, 2, 3, &c., seconds, provided gravity had not drawn it down. But as we have seen, gravity draws it down 15 feet in 1 second; $4 . 15 = 60$ feet in 2 seconds; and $9 . 15 = 135$ feet in 3 seconds. The height at the end of 1 second is, therefore, $150 - 15 = 135$ feet; at the end of 2 and 3 seconds, $300 - 60 = 240$ feet, and $450 - 135 = 315$ feet. In 5 seconds it would have reached a height of 750 feet, but being drawn down $15 \times 5^2 = 375$ feet by the force of gravity, it is actually at an elevation of $750 - 375 = 375$ feet, and now begins again to fall.

Let us consider this more generally. In t seconds the body would ascend to the height $n\,t$, owing to its original velocity n; but having been drawn down $\frac{g}{2}\,t^2$ by gravity, its actual height is

$$h = n\,t^2 - \frac{g}{2}\,t^2.$$

The body ascends as long as $n\,t$ is greater than $\frac{g}{2}\,t^2$.

As the highest point of its course is attained when $t = \frac{n}{g}$, we find the elevation of the body at this moment, if in the above given formula for h, we substitute this value in place of t; we then have

$$h = \frac{n^2}{g} - \frac{g}{2}\frac{n^2}{g^2} = \frac{n^2}{g} - \frac{n^2}{2g} = \frac{n^2}{2g}.$$

But in $\frac{n}{g}$ seconds a body, falling free, traverses a space

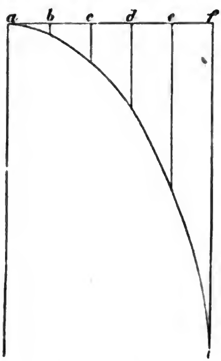
$$\frac{g}{2} \cdot \frac{n^2}{g^2} = \frac{n^2}{2g}.$$

Hence it follows that the body requires exactly as much time to fall as to rise.

Let us seek the velocity with which the falling body regains the point from whence it began its ascending motion. We shall find it from the formula $v = g\,t$; but as the time of falling $t = \frac{n}{g}$ it follows that $v = n$, that is *the body comes down with the same velocity with which it began to rise*; or, *in order to impel a body vertically to a height* h, *we must impart to it an initial velocity, exactly as great as that acquired by it, in its free fall from the height* h.

Projectiles.—If a body be thrown in any other than a vertical direction, it will describe a curved line, the form of which may be easily deduced from the laws of falling. Let us assume the simplest case, for instance, that the body be impelled by any force in an horizontal direction. If there were no such force as gravity, the body would continually move in an horizontal direction, and with an uniform velocity.

FIG. 134.



By reason of the first impelling force, it would traverse the space $a\ b$ in 1 second, the equally large space $b\ c$ in 2 seconds, and so on, and must consequently at the end of the 1st, 2nd, 3rd, &c., second, have reached the points b, c, d, &c. But it has sunk from the force of gravity; in the first second it fell 15 feet, consequently at the end of that time instead of being at b, it will be 15 feet

below it. At the end of the next second, it is 60 feet below c; at the end of the third, 135 feet below d, &c. The curved line described by the body in this manner, is a parabola.

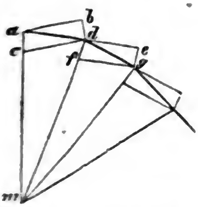
If an impulse be given in any other direction, the course described may in like manner be obtained by construction.

The course described by a projected body varies in consequence of the resistance of the air from a true parabola.

Central motion.—We must now consider motions produced by gravity, where the directions of the force of gravitation in various points of the course are no longer parallel. Motions such as these are observed in the revolution of the moon round the earth, and of the planets round the sun.

If we suppose the point a (Fig. 135), to have received an impulse in the direction $a\ b$ from any momentarily acting force at the beginning of its course, while it is driven towards the point m by a constantly acting force of attraction, it will neither move in the directions $a\ b$ nor $a\ c$, but in another direction $a\ d$, which may be ascertained by the law of the parallelogram of forces. In order to make the consideration more simple, we will assume that the constantly attracting force directed towards m, acts by impulses at short intervals, and this will be found the more nearly to approach the truth, the smaller we imagine these intervals to be. If the laterally directed impulse alone would drive the material point in a short space of time t from a to b, and the attracting force, acting alone would urge it in the same time to c, it would move under the influence of both forces in the instant of time t, from a to d. Arrived at d, it would move further in the direction $d\ e$, and in the time t, the space $d\ e$ would be exactly as great as $a\ d$, if the attracting force did not act again in such a manner, as if the body had received an impulse in d, which acting alone would have led it in the time t from d to f. By this second action of the attracting force, the body is again turned from the direction $d\ e$, and urged to g.

FIG. 135.



From this we can easily understand, that if the body have received at a, a laterally directed impulse, while the attracting force acts at small intervals, it must describe a polygon, which approaches more nearly to a curved line in proportion to the smallness of the intervals. When the attracting force constantly

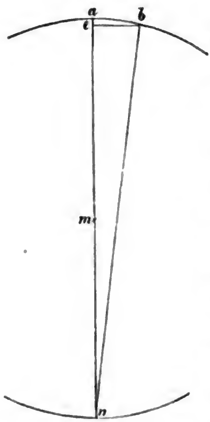
acts as it does in nature, the course will truly be a curved line, the nature of which will depend upon the relation of the influencing forces.

The force that constantly urges a body towards a central point of attraction, is designated the *centripetal* force. If at any moment, the centripetal force were to cease acting, the body would from that instant continue to move in the direction of a tangent, and the force thus acting is named the *tangential force*.

The figure described by the course of a body will be a circle, an ellipsis, &c., according to the relation between the *tangential* and *centripetal* forces.

Let us seek to determine the amount of the centripetal force, that urges the moon in its motion round the earth towards the central point of the latter. The earth's circumference is 40 millions of metres; but as the radius of the moon's orbit is equal to 60 radii of the earth, the circumference of the moon's orbit is 2400 millions metres. This course it traverses in 27 days, 7 hours, 43 minutes, or what is the same thing in 39,343 minutes. In every minute, therefore, the moon passes over a space of $\frac{2400,000,000}{39,343} = 61,000$ metres. Fig. 136 represents the arc $a\ b$ of 61,000 metres, traversed by the moon in one minute; $a\ c$ is, therefore, the amount of space through which the moon would approach the earth in one minute by the force of gravity, if the action of the tangential force were suddenly destroyed.

FIG. 136.



We may compute the magnitude of the distance $a\ c$, by assuming that the arc $a\ b$ is a straight line from which it actually deviates but slightly: $a\ b\ n$ is then a right angled triangle, $b\ c$ is a perpendicular let fall from the right angle upon the hypothenuse; and under such circumstances, in accordance with a known proposition of geometry, $a\ b$ is a mean proportional between $a\ c$ and $a\ n$: consequently

$$a\ b^2 = a\ c \times a\ n$$

and hence

$$a\ c = \frac{a\ b^2}{a\ n}.$$

Now we have seen that $a\,b = 61000^{m}$; but $a\,n$ the radius of the moon's orbit is $763{,}950{,}000^{m}$. If we put this value in the place of $a\,b$ and $a\,n$ into the last equation, we have

$$a\,c = 4{,}87^{m},$$

that is, we find the attraction of the moon towards the earth amounts to 4,87 metres in a minute.

But what is the force producing this action? Is it the same force that makes the stone fall to the earth? If we assume that the force of gravity observed upon the surface of the earth, extends its influence beyond our atmosphere, acting even on the moon, we can easily comprehend that its intensity must diminish with the distance from the earth. By a simple mode of deduction, which we shall consider more attentively when we treat of light, we find that the intensity of all actions emanating from one point stands in an inverse relation to the squares of the distance. Consequently at double, triple, quadruple the distance from the earth's centre, the intensity of the force of gravity will be diminished 4, 9, 16 times.

At the moon it is, therefore, 60^2 or 3600 times weaker than at the surface of the earth, because the moon is removed 60 times farther from the earth's centre. If according to this, the space fallen through in the first second on the earth's surface were 4,9 metres, the space fallen through by the moon towards the earth in one second would be $\frac{4{,}9}{60^2}$ metres, and consequently in a minute, that is sixty seconds, it would be $\frac{4{,}9}{60^2} \cdot 60^2 = 4{,}9$ metres. That is the space by which the moon approaches the earth in one minute must be as great as the space fallen through in the first second of fall upon the earth's surface.

If we compare the space, viz. 4,9 metres, calculated for the fall of the moon towards the earth in a minute, with the 4,87 metres deduced from astronomical observations, we shall really only find a very small difference, which would wholly disappear if we had not for the sake of the simpler computation, taken only approximating valves into consideration. Thus we have entirely neglected the seconds in giving the time of the moon's revolution, and have assumed the distance of the moon from the earth to be equal to 60, although it really is 60,16 radii of the earth.

In this manner the motion of the planets round the sun may also be explained, and it is thus one and the same force that urges the

stone to the earth, and acting through the whole space of the heavens, maintains the harmony of our planetary system.

For the knowledge of this vast law of general gravity, we are indebted to the penetration and the unwearying industry of *Newton*. Had he done nothing more, this single discovery would have sufficed to immortalize his name.

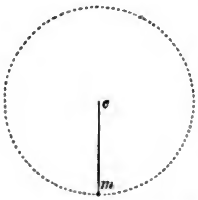
In the same manner in which we have developed the amount of the centripetal force in the motion of the moon, we may also obtain a general expression for these forces. Let us assume, as a measure of the centripetal force, the space $a\ c$, through which the body in its central motion, in a unit of time, will be urged towards the centre of attraction, and let us designate it by p, then as has been already proved $p = \frac{a\ b^2}{a\ n}$. Now the arc $a\ b$ is that which the body actually describes in the unit of time, therefore, $a\ b = \frac{2\ \Pi\ r}{t}$, if r be the radius of the spherical orbit, and t designate the time of revolution. Further $a\ n$ is the diameter of this orbit, and consequently equals $2\ r$. If we substitute these values of $a\ b$ and $a\ n$ in the above equation, we find that

$$p = \frac{2\ \Pi^2\ r}{t^2}.$$

That is to say: if two bodies move in different orbits, and with different times of revolution, *the centripetal forces will be as the radius of the circles described, and inversely as the squares of the times of revolution.*

If a small sphere which we must suppose devoid of weight be fastened to the end of a string at m, and turned round the point c, so that it describes a circle round the centre c, the string will constantly have to sustain a tension increasing with the speed of the revolution. If, at any moment, the string were severed, the ball instead of moving on in a circle, would by reason of its inertia fly off at a tangent from its former path.

FIG. 137.



The cause of the tension sustained by the string is designated *centrifugal force.*

But as the resistance of the string produces the same effect as the centripetal force considered under the head of central motion, it is clear that the centrifugal force is equal, and opposed to the centripetal force, and that all that has been said of the latter

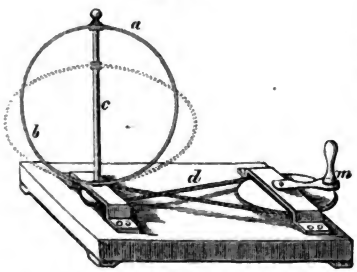
applies equally to the former, that is, that the centrifugal force increases in the ratio of the radius of the orbit, and inversely to the square of the period of revolution. As a matter of course the tension of the string, and consequently the centrifugal force must be proportional to the revolving mass.

Centrifugal force prevails wherever there is a rotation round a fixed axis, and the separate particles are prevented in any way deviating from this axis. Such a centrifugal force must, therefore, be occasioned by the rotation of the earth round its axis. As the time of rotation is the same for all points of the earth, while the different points are not equi-distant from the axis of rotation, it is clear that this centrifugal force is not equal upon the earth's surface, but must be as the distances from the earth's axis; consequently, it is at its minimum at the poles, and at its maximum at the equator.

This centrifugal force which is greatest at the equator, and diminishes as it approaches the poles, acts against gravity, and lessens its intensity. We may easily compute the amount of velocity with which the earth must rotate on its axis, in order that the centrifugal force engendered at the equator may fully counteract the effect of gravity.

The apparatus represented at Fig. 138, is particularly well calculated for experiments concerning the centrifugal force. We will, however, limit ourselves to one experiment, explaining the flattening of the earth at the poles.

FIG. 138.



By help of the handle *m*, the horizontal disc below it is made to revolve. The rotation of the disc is transmitted by the thread *d* to another disc of a smaller radius. I will of course be evident that the smaller disc must make more revolutions than the larger one in the same period of time, these bearing the same relation to each other as the radii of the two discs. The vertical axis *c* fastened in the middle of the smaller disc turns with it. A spring *a b* fastened by its lower end to the axis, but admitting of its other extremity being freely moved up and down, and which in a state of rest forms a spherical figure,

will by rapid revolution assume an elliptical form, owing to the centrifugal force acting with the greatest intensity upon those points of the spring that are the furthest removed from the axis.

Of the Pendulum.—The common pendulum consists of a heavy ball suspended to the end of a flexible thread. If we disturb the equilibrium of the pendulum, that is if we remove it from its vertical position, it will, when left to itself and without receiving any impulse, continue to oscillate in a vertical plane. If we bring the pendulum into the position *f a*, the ball will describe an arc *a l*, reaching *l* with such velocity as to be carried forward as high as *b* on the other side, that is to say to the elevation of the point *a*; from *b*, the pendulum again traverses in a reversed direction the arc *b l a*, and in this manner continues its oscillations. The velocity of the pendulum constantly increases with its descent and diminishes with its ascent; at the moment, therefore, in which the pendulum passes the point of equilibrium it has attained its greatest velocity.

FIG. 139.

The motion from *a* to *b*, or from *b* to *a* is termed an *oscillation*, from *a* to *l* is a semi-descending oscillation, from *l* to *b* a semi-ascending oscillation.

The *amplitude* of an oscillation is the magnitude of the arc *a b* expressed in degrees, minutes, and seconds.

The *time* of an oscillation is the time necessary for the pendulum to traverse this arc.

At the first glance we might conclude from this experiment that the motions of a pendulum must always continue, for if starting from *a* it be borne up to an equal height *b* on the other side, it must, starting from *b* also ascend to *a*, and thus continue the same course, a second, third, and fourth time, and thus on to eternity.

This deduction would be perfectly correct, if *b* were absolutely at an equal elevation with *a*; but the friction at the point of suspension *f*, and the resistance of the air that must be displaced by the ball, hinder the latter from ascending exactly to the same height from which it descended. This difference becomes only appreciable after a series of oscillations, and instead of wondering that the motion does not continue for ever, we ought rather to be

surprised that it lasts so long, for a pendulum can go on oscillating for hours together.

Laws of the oscillations of the Pendulum.—The laws of the oscillations of simple pendulums, are as follows:

1. The duration of the oscillation is independent of the weight of the ball and the nature of its substance.

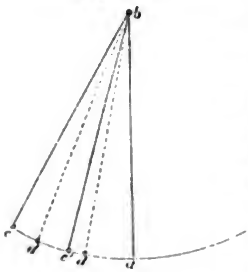
To prove this, we must construct several pendulums of equal length, the ball of one being of metal, of another wax, of a third wood, &c., and we shall then find that all have equal durations of oscillation.

When gravity makes a pendulum oscillate, it acts upon every atom of the matter composing the ball; each atom of the ball is acted upon by its own gravity, and consequently an increase of the atoms can have no influence on the velocity of the oscillations. If we could suspend a single atom of iron to a thread devoid of weight, it must oscillate just as fast as if we attached to it two or three atoms, or even a ball of iron. Gravity, however, might act otherwise upon a molecule of wax than upon a molecule of iron. That it does not do so, that gravity acts alike on a molecule of gold, platinum, wax, iron, &c., is proved by the experiment with the pendulum. The already mentioned experiment on falling in a *vacuum* is but a rough illustration of the fact, as we have only to observe the action of gravity during an extremely short period of time. The pendulum, however, enables us to watch the influence of gravity upon different bodies during many hours together.

2. The duration of small oscillations of the same pendulum is independent of their magnitude. If, for example, a pendulum vibrates 4—5°, the duration of the oscillation is the same as if it vibrated only 1°.

This law may be thus developed. If the angle of deviation be not too large, the inclination of the course towards the horizon will be proportionate to the distance from the point of equilibrium. If we suppose a tangent drawn at c to the arc of the circle, it will form an angle with the horizon twice as great as the angle made with the horizon by the tangent at c', provided the arc $c'\ a$ be half as great as the arc $c\ a$. If, therefore, the pendulum begin its motion at c, the acce-

FIG. 140.



lerating force is twice as great as when it begins its descent from c'; the arc $c\ d$ which we will assume to be so small that it may be considered a straight line, and the arc $c'\ d'$ only half the size, will, therefore, be traversed in an equal period of time, if motion begin at one time in c, and at another in c'.

If we suppose two equal pendulums suspended to an axis, the one raised to c, the other to c', and both going off simultaneously, they will reach the points d, and d' at the same time. But the accelerating force at d is twice as great as that at d', besides which the pendulum reaches a point d with twice as great a velocity as that with which the other passes the point d', and hence it follows, that also in the next short interval of time, the one pendulum will have traversed twice as much space as the other. By pursuing this mode of deduction, we at last find that both pendulums must arrive simultaneously at a.

This reasoning may also be applied if the relation of the angle of deviation be not exactly between 1—2°, since the accelerating force is always proportionate to the distance from the position of equilibrium for small angles of deviation; and thus it may generally be proved, that within certain limits the deviation of the oscillation is independent of the magnitude of the angle of deviation.

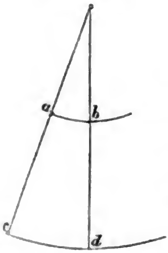
In order to confirm this law by experiment, we must accurately determine the time necessary for a pendulum to make several hundred oscillations.

If this observation be made at the beginning of the motion, when the amplitude is 4—5°, subsequently when it only amounts to 2—3°; and lastly when the oscillations have become so small as to require the aid of the lens for detecting them, we shall find that the oscillations are truly isochronous at these three stages.

3. The durations of the oscillations of two pendulums of unequal length are as the square roots of the lengths of the pendulums.

We must suppose the arc $a\ b$ described by the oscillation of a pendulum to be divided into so many parts that each division may be considered as a straight line. If now the angle of deviation of a longer pendulum is equally large, the arc of oscillation $c\ d$ must be to the arc of oscillation $a\ b$ as the lengths of the pendulums to each other. If we suppose the arc $d\ c$ to be divided in an equal number of parts as the arc $a\ b$, these separate parts will be to each

FIG. 141.

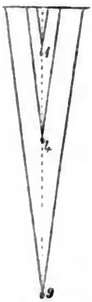


other as the lengths of the pendulums. If, therefore, one pendulum be four times longer than the other, the subdivisions of the arc *d c* will also be four times larger than those corresponding divisions of the arc *a b*. The angles made with the horizon by the first, second, and third divisions of the arc *a b*, are equal to the angles made with the horizon by the first, second, and third divisions of the arc *c d;* the accelerating force is, therefore, also the same on the corresponding parts of *a b* and *c d*.

But if different spaces be traversed with equal accelerating forces, we know from the formula $s = \frac{g}{2} t^2$, that the times of falling arc as the square roots of the spaces, if, therefore, each of the parts of *c d* were two, three, or four times as large as the corresponding divisions of *a b*, the time in which a division of *c d* will be traversed, must also be $\sqrt{2}$, $\sqrt{3}$, $\sqrt{4}$, $\sqrt{n}$ times as long as the period occupied in traversing the corresponding portions of *a b*. But as this is true of all the parts, so it is also true of their sums, or in other words, the duration of the oscillation is proportionate to the square root of the length of the pendulum.

In order to confirm the accuracy of this third law by experiment, we will take three pendulums of different lengths. If, for instance, the lengths are as the numbers 1, 4, 9, the corresponding times of oscillation will be as the numbers 1, 2, 3. The most convenient mode of exemplifying this, is by attaching the balls to a double thread as seen in the accompanying figure. While a pendulum, four feet in length makes one oscillation, the pendulum which is four times smaller than the former makes two oscillations, and whilst a pendulum, one foot in length moves three times backwards and forwards, another, nine feet long will only make one backward and forward motion.

FIG. 142.



The length of a simple pendulum oscillating seconds, is 994 millimetres; if, therefore, the length of a second's pendulum had been taken as the unit of length, it would have deviated but little from the metre.

Quantity of Motion.—Most forces that set bodies in motion act only directly upon a small portion of the molecules composing the

body. In striking a billiard-ball we only touch a few points of the surface. If the wind drive a ship, it only presses upon the sails, and when a ball is discharged by powder, the gases which give the impulse on being liberated, press only upon half the surface of the ball. Notwithstanding this, all parts of the body move, whether they be directly acted upon or not. Motion must, therefore, be uniformly distributed to all the molecules, as all move simultaneously. The molecules directly struck, impart an impulse to those nearest them, and so on, until the whole mass is set in motion. A certain, although inappreciably small portion of time is necessary for the transmission of motion from one molecule to the whole mass.

If a force act upon a body, it will have produced its effect as soon as motion has been distributed to all portions of the mass, and these latter move with a common velocity, the force being then transferred, as it were, to the body, and diffused through it.

If, therefore, a body be projected by the hand, by the release of a spring, by a quick push, or by means of a sudden explosion, it will continue to move on after the force has ceased to act upon it. If nothing were to oppose it in its course, neither air, water, nor any other body, and if no force whatever were acting upon it, it would move in the direction of the first impulse with uniform velocity after a hundred years in the same manner that it did after the first second. We may say that the activity of such a body is momentary, while its effect lasts for ever.

Thus the body to a certain extent absorbs the force acting upon it, and we can, therefore, easily understand how the same force acting upon different bodies must call forth very different motions.

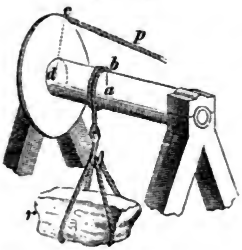
A quantity of powder, sufficient to discharge a musket-ball, would scarcely raise a bomb; while a bow capable of sending a light arrow to a great distance, would not be able to send off a heavy one with as much speed. We say commonly that the gravity of the body gives rise to this difference, but this is an incorrect assertion, since we might be erroneously led to conclude that if a body were to cease to be heavy, the same force would move all bodies with equal velocity. Let us suppose, for a moment, that bodies are without gravity, and assume that there is no air present, or other hinderance of motion; the musket ball would still be urged on faster than the bomb, because the same force must produce a degree of speed, smaller in proportion as the mass

of matter to be moved increases in size. It is one of the fundamental principles of machines, *that the same force, acting upon different bodies, imparts to them a velocity inversely proportionate to their masses; that is to say, in an inverse ratio to the quantities of matter composing them.* If, therefore, the same force discharged in succession leaden balls, whose volumes, and likewise whose masses were as the numbers 1, 2, 3, 4, &c., it would impart to them the velocities 1, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, &c., so that a mass ten times larger would only have $\frac{1}{10}$th the velocity. On multiplying each of these masses with its velocity, we always obtain the same product for the first $1 \times 1 = 1$ for the second $2 \times \frac{1}{2} = 1$, &c. The quantity thus obtained by multiplying a body by its velocity is termed *quantity of motion*. The same force also produces always the same quantity of motion on whatever body it acts.

In order to obtain a clear idea of the mode of action of various machines, we must compare the quantity of motion, which the applied force is capable of producing with the effect obtained by means of the machine. It would be a vulgar error to regard a machine as a source of force, or to believe that the quantity of motion could be increased by machinery. *By machines the nature of the motion is simply changed, without its quantity being in the least increased thereby.*

A weight of twenty-five pounds may be easily lifted two feet and a half in a second, by means of a rope swung round a simple pulley. But if the rope, pulled by the workman, were passed round a wheel, (Fig. 143) and the load attached to an axle of four times smaller diameter, a fourfold larger weight might be raised by an equal application of force, although with a speed four times smaller. If we examine the mode of action of other machines, as the screw, the pulleys of various wheel works, we shall always attain to the same result, viz. that what we gain on the one side in force, we lose on the other in speed, and that consequently the quantity of motion is not at all increased by machines.

FIG. 143.



If a body in motion come into contact with another at rest, but which is easily moved, it will impart to the latter a portion of its motion; but the total quantity of motion is not thereby altered;

and if the striking body rebound in consequence of elasticity, and the impulse were centrally applied, both bodies will move on in the same direction after coming into contact. If the mass of the body at rest be equal to that of the one striking it, the speed of motion will be diminished to the half after contact, as the mass has been doubled. From this we may easily see that in order to find the relation of the speed before contact, to that of the speed subsequently manifested, we have only to divide the mass of the body moved by the sums of the masses of the body moved, and the body at rest. If, for instance, a musket ball of $\frac{1}{20}$ lb. were to strike, with a speed of 1300 feet in a second, a ball of 48 lbs. at rest, but easily moveable and suspended to a long line, the common speed after the blow would be to 1300 as $\frac{1}{20}$ is to $48+\frac{1}{20}$, or as 1 to 961; that is, it would be only about $\frac{1300}{961}$ or about $1\frac{1}{3}$ feet in a second.

If a similar musket ball were to strike against a large block of stone or a rock, it would also impart a motion to it, but the speed would be very inconsiderable; for, if the block of stone were 500 lbs., the common speed after the contact as may easily be reckoned, would be only one inch in the second. But friction, however, soon destroys this motion which by degrees distributes itself to all neighbouring bodies, and finally to the whole earth, and thus entirely disappears.

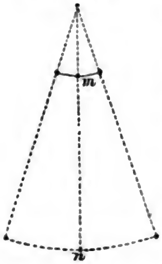
Motion, therefore, distributes itself to other bodies, but is not lost. If it appear wholly destroyed, the reason is, that by its gradual distribution to other bodies, it finally becomes imperceptible. Motion is necessary to destroy motion; resistance only scatters without destroying it.

The (material) Pendulum.—The above developed laws apply strictly speaking only to an ideal pendulum. Such a pendulum we may conceive, but we cannot construct, for it must consist of a simple thread devoid of all weight, and having at its extremity only a heavy point.

Every pendulum not corresponding with both these conditions is a compound pendulum. An inflexible rod devoid of weight on which are two heavy molecules, *m* and *n* would consequently be a compound pendulum.

The molecule *m* nearer to the point of suspension than *n*, has a tendency to vibrate more rapidly, but as both molecules are combined, *m* will hasten the motion of *n*, and conversely *n* will

FIG. 144.



retard that of *m;* the vibrations will on that account move with a velocity varying between the degrees of velocity with which each of the molecules *m* and *n* would oscillate alone. They are equal to the oscillations of a simple pendulum longer than *f m*, and shorter than *f n*. It is the same with every material pendulum. Those parts lying nearest the central point of vibration in the pendulum have their motion retarded by the most remote, while the latter are accelerated by the parts most contiguous to the point of suspension. There must consequently be a point in every compound pendulum, which is not acted upon by the rest of the mass of the pendulum, vibrating exactly as fast as a simple pendulum, whose length is equal to its distance from the point of suspension. This is called the centre of oscillation. If we speak of the length of a compound pendulum, we understand by the term the distance of this point from the point of suspension, or what is the same thing, the length of a simple pendulum of an equal time of oscillation.

A pendulum consisting of a fine thread at whose lower end a ball, or a double cone, of a substance of great specific gravity is attached, approaches most nearly to the simple pendulum. If the thread be somewhat long, and the diameter of the ball somewhat small in proportion to the length of the pendulum, we may without any serious error take the centre of gravity of the ball as the point of oscillation of the pendulum, or in other words, we may take such a pendulum for a simple one.

In every actual pendulum, however, which differs more considerably from the form of a simple pendulum; the centre of gravity is by no means the centre of oscillation; it is in most cases a difficult problem to ascertain by calculation where the centre of oscillation lies in an actual pendulum, because in a computation of this kind, we must not only have regard to the accelerating force of gravity of the individual points lying at different distances from the point of suspension, but also to the resistance opposed to an acceleration of motion owing to the inertia of their mass.

The simplest way of seeing that the centre of oscillation of an actual pendulum cannot coincide with its centre of gravity is by observing a pendulum in which a portion of the mass lies above the point of suspension. Such a pendulum vibrates considerably slower

than it would do, if its centre of gravity were the centre of oscillation.

Fig. 145 represents an evenly divided rod provided in the middle with an edge similar to what forms the fulcrum of the beam of a balance. If now we fasten a leaden mass weighing two pounds, one decimetre above, and another of the same weight equally far below this edge, and place the edge upright on its support, the rod with its weights will be in a condition of indifferent equilibrium, for the centre of gravity of the system corresponds with the fulcrum; as soon, however, as we attach a small extra weight to the lower end of the rod, the whole becomes a pendulum. But the oscillations of this pendulum are much slower than those of a simple pendulum of the length *a b*, for the only force that sets the whole system in motion is the gravity of the lower leaden weight; this, however, has not only its own mass to move, but also the masses of the weights at *c* and *d*.

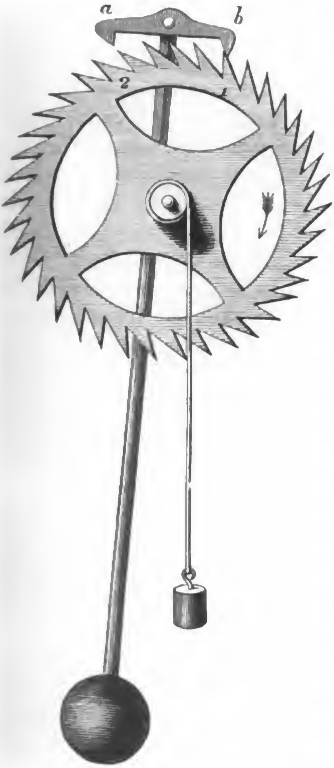
FIG. 145.

We thus easily perceive why the beam of a balance, which may be considered as a pendulum, vibrates so slowly, although its centre of gravity is close to the point of suspension, and why it must vibrate very rapidly if the centre of gravity were really the centre of oscillation.

The Pendulum Clock.—The most important application of the pendulum is for the regulation of clocks. Every clock must have an accelerating force to produce and maintain motion. From what has been said, however, concerning accelerating forces, it is evident, that if some other equal force, or hinderance of motion do not oppose the accelerating force, motion cannot remain uniform, but will become faster and faster as in a falling body. In our large upright clocks, this accelerating force is produced by weights, hung to a line passed round an horizontal axle. If the weight be drawn down by its gravity, the axle will be turned by the line, and the whole machinery set in motion. But the motion of a falling weight is an accelerating one, consequently the check must at first go slowly, then more and more quickly, unless its course were regulated, and this regulation is effected by means of the pendulum.

Fig. 146 exhibits the manner in which the pendulum regulates the going of a clock. A toothed wheel is fastened to the axis to

FIG. 146.



which the line with the weight is attached. The axis, round which the pendulum vibrates is above this wheel, and to this axis is secured a beam *a b*, which catches the teeth of the wheel on either side. The figure represents the pendulum in the position, where it is at the extreme left side. The wheel is turned by the weight in the direction of the arrow, but cannot go on, having the tooth 1 held by the tooth *b* of the lever; as soon, however, as the pendulum vibrates back again, *b* rises, and the tooth 1 is suffered to pass, but the motion of the wheel is again immediately arrested, because the tooth *a* at the other end of the lever now descends, pressing against the tooth 2 of the wheel; thus the wheel can move one tooth at every oscillation, and the same every time the pendulum returns, and thus the motion of the wheel is regulated by the movements of the pendulum. Such a contrivance is called an *escapement*.

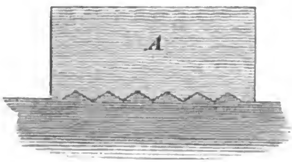
In watches, the weight is replaced by a tensely drawn steel spring, and the pendulum by a fine spring vibrating, owing to its elasticity round its point of equilibrium. Clocks made in Paris, and which there went quite well, were found to loose when brought near the equator, so that it was necessary to shorten their pendulums. Hence it follows that the same pendulum goes more slowly at the equator than near the poles, and consequently that the action of gravity is less at the equator than at the poles. This is owing to two causes; first the flattening of the earth, and secondly the centrifugal force produced by its rotation round its axis, and which is stronger at the equator.

Impediments to Motion.—A resistance already often spoken of, and which exercises a considerable influence upon almost all motions, is friction. In order to propel a load of moderate size along a horizontal plane, a considerable application of force is necessary arising entirely from the resistance of friction. If the plane, on which the mass is to be propelled, as well as the under surface of the load, be perfectly hard and smooth, (which is never the case in nature) the smallest force might set a very large mass in motion, and once impelled, the load would move on with uniform speed on the horizontal plane.

Friction arises incontestibly from the elevations of one of the surfaces, entering into the depressions of the latter. If now motion is to occur, the projecting parts must be torn away from the mass of the body, or the one body must be continually lifted over the inequalities of the other. The first occurs if one or both the rubbing surfaces are very rough. If, however, the rubbing surfaces can possibly be smoothed, the last named mode of action almost exclusively takes place.

The accompanying figure may serve to explain the manner in which resistance to motion arises, if a body must be lifted over small inequalities. The lifting of the body *A* is effected by raising the lowest points of the projections of *A* to the summit of the inequalities of the under layer, whence they must again slide down, and the same raising and lowering be repeated. The resistance opposed here by *A* to the motion, is no other than what must be overcome to draw it up an entirely smooth inclined plane.

FIG. 147.



If this view of friction be correct, the laws relating to it must admit of being proved by experiment.

In order to overcome friction we must, exactly as in drawing the body up an inclined plane, apply a force equal to an aliquot part of the load. The number that gives the relation of the force to the weight is termed the *co-efficient of friction.* It naturally depends upon the peculiarities of the rubbing surfaces, and can be determined by experiment.

If, for instance, we would propel a load of one cwt. upon an horizontal layer of iron (on the line of a railroad for instance), and if the under surface of the truck were also iron, a force of 27,7 lbs.

would be necessary, that is to say the same expenditure of force that would be requisite for lifting 27,7 lbs. vertically up. When iron rubs on iron, the resistance of friction is as we see 27,7 per cent, and the coefficient of friction in this case is 0,277. In order to ascertain the coefficient of friction for different bodies, we may make use of an apparatus as seen at Fig. 10. The board *R S* is placed in a horizontal position. Suppose this board to be of oak, we lay a block of oak upon it, whose under surface must also be well planed, weighing 1000 grammes; a line is attached to this block of oak, and passed round a pulley as in the experiments of the inclined plane, carrying a light scale-pan. This latter will not be sufficient to produce motion, which will not begin before the weight of the scale pan, and of the weights together amount to 418 grammes. We obtain by this experiment the coefficient of friction of oak upon oak, and find them to be 0,418.

If we alter the substance of the body to be moved, as well as of the body supporting it, we may ascertain the coefficient of friction of different bodies. The following table contains some of the most practically important coefficients of friction.

Iron upon iron	0,277
Iron upon brass	0,263
Iron upon copper	0,170
Oak upon oak	0,418 = 0,273 +
Oak upon pine	0,667
Pine upon pine	4,562

The resistance of friction may be diminished by the application of well chosen oleaginous substances. Oil is the best for metal, white tallow answers best for wood.

In woods it is by no means a matter of indifference which way the fibres run; friction is much less considerable where they run across (+) than where they are parallel (=).

From what has been said, it is directly shown that friction is always proportionate to the weight. If, for instance, in the above experiment we had taken a block of oak weighing 2000 grammes, we should have had to attach 836 grammes to the rope, in order to overcome the friction.

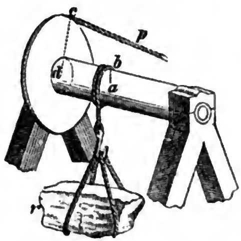
The size of the surface in contact cannot, according to the above views, exert any influence on the amount of friction; this may be

also proved by experiment. Suppose that the block of wood have lateral surfaces of different size, no difference will be found in the result, whichever surface of the block touch the wood.

The above described kind of friction is termed *sliding friction,* in order to distinguish it from the *rolling friction,* which we proceed to consider more attentively.

Sliding friction always occurs where pins or axes revolve in their supports; in order the better to take into account the effect of friction in this case, we need only consider that it acts precisely like a corresponding weight suspended to a string passed round the same axle. Let us by way of illustration examine the effect of friction on the windlass. Let the weight of the axle with every thing that is fastened to it, be about 75 lbs., the stone to be raised 100 lbs., and the force acting on the circumference of the wheel be 25 lbs., then the combined pressure sustained by the props of the axle, will be $75 + 100 + 25 = 200$ lbs. If the props be of brass, but the extremities of the axle be of iron, the resistance of friction acting on the circumference of the ends of the axle will be 26,3 per cent.; the effect of friction is, therefore, the same as if in place of this we had passed a line round the ends, in the same direction as the line bearing the weight, and had attached to it a weight $200 \times 0{,}263$ or 52,6 lbs., or as if the load acting at the circumference of the axle had been $\frac{52{,}6}{5}$ or 10,5 lbs. larger, provided that the diameters of the rods were $\frac{1}{5}$ of that of the axle. Thus about 10 per cent of the force applied, is lost in this windlass, in overcoming the resistance of friction.

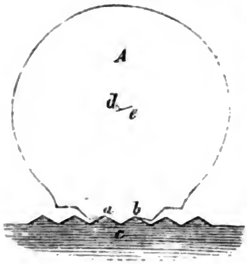
FIG. 148.



It now remains to notice *rolling friction.* Rolling friction occurs where a round body, as a ball, or a cylinder rolls along a surface. Here the supporting under surface comes always in contact with new points of the rolling body. The resistance that arises here is by far less than the resistance of sliding friction, as may be seen from the following consideration.

If we wish to propel the round body *A* over the surface on which it rests, we must begin by drawing it to a little inclined

FIG. 149.



plane *c b*, when its centre of gravity will be raised as much as *c* lies below *b*. But by rolling on the body *A*, it will turn round the point *b*, by which its centre of gravity will only be raised from *d* to *e*. The difference of height, however, between *d* and *e*, is much less than the difference of height between *c* and *b*. Let us suppose a spherical arc to be drawn round the central point *d*, and through the points *a* and *b*, the lowest point of this arc will be as much below *b*, as *d* is below *e*. But as the lowest point of the arc *a b* still lies high above *c*, we may easily understand that the alternate rising and falling of the centre of gravity, is much less considerable in rolling than in sliding friction. We also, however, perceive that the resistance of friction depends mainly here upon the radius of the rolling body. The larger this radius is, the smaller will be the resistance. In other respects, resistance is here likewise proportionate to the load.

In the wheel of a carriage there is rolling friction at the circumference of the wheel, but sliding friction at the axles. Both resistances become smaller in proportion to the larger diameter of the wheels.

In both kinds of friction adhesion has considerable influence.

In a locomotive, the middle wheels, the so called driving wheels are turned by the force of the steam engine; the whole carriage rolls on in consequence of this, for if it were to remain at rest, the wheels could not revolve without the occurrence of a considerable sliding friction between the wheels, and the iron on which they ran, whilst by rolling on the incomparably smaller, rolling friction has alone to be overcome. If a locomotive be attached to a number of carriages, a certain resistance of friction must be overcome during the continuance of motion, rolling friction at the circumference, and sliding friction at the axles. All these resistances must be overcome if the carriage is to be drawn onward.

It is evident that the number of carriages attached might at last be so increased that the locomotive would no longer be able to draw them; in this case, therefore, the wheels of the locomotive would revolve without its being borne forward, when the consider-

able friction of the sliding friction, at the circumference of the driving wheels, would have to be overcome by the force of the machine.

The train, therefore, can only proceed if the sum of all the resistances of friction of all the carriages is smaller than the resistance of the sliding friction from the rotation of the driving wheels of the locomotive at the circumference which would exist were there no forward motion.

From these considerations, it follows, that the load which a locomotive is capable of drawing, depends not only upon the force of its steam engine, but always upon its weight. If we assume that two locomotives have equally strong machines, but that the one is heavier than the other, a larger weight may be propelled by the heavier of the two.

CHAPTER II.

LAWS OF THE MOTION OF LIQUIDS.

If we make an opening in the lateral wall, or the bottom of a vessel filled with liquid and open at the top, and if the aperture thus made be small in comparison with the dimensions of the vessel, the liquid will flow out with a velocity whose intensity will be in proportion to the depth of the opening below the surface of the liquid. The connection existing between the velocity of the escaping liquid, and the height of the pressure may be most simply expressed in the following manner. *The velocity of the escaping liquid is exactly as great as the velocity a freely falling body would acquire, if it were to fall from the surface of the liquid to the aperture through which the liquid escapes.*

This proposition is known by the name of the *Toricellian* theorem. It may be explained in the following manner.

FIG. 150.

If the liquid layer, $a\ b\ c\ d$ (Fig. 150) immediately above the opening $a\ b$, were to fall down without being accelerated by the liquid pressing over it, it would flow from the opening with a velocity corresponding to the height $a\ c$, which we will designate as h. This velocity is $c = \sqrt{2\,g\,h}$. But now the escaping stratum is not only accelerated by its own gravity, but by the gravity of all the liquids pressing upon it. The accelerating force of the gravity g is, consequently, to the accelerating force g', actually propelling the liquid particles, as $a\ c$ is to $a\ f$, or as h is to s if the height of pressure be designated by s, that is

$$h : s = g : g',$$

and, therefore, the accelerating force g' acting upon the liquid layer flowing out is $= \frac{g}{h} s$. But if the accelerating force acting

upon this layer be g' and not g, then its velocity $c' = \sqrt{2\,g'\,h}$; and if we add the value of g' to this value of c', we obtain as the value of the velocity of the escaping fluid

$$c' = \sqrt{2\,g\,s}.$$

But this is the same velocity as that acquired by a body falling freely from a height s.

From this proposition it immediately follows that:

1. *The velocity of the efflux depends only upon the depth of the aperture below the surface, and not upon the nature of the liquid.* At equal heights of pressure, water and mercury will, therefore, flow out with equal velocity. Every layer of mercury will certainly be driven out by a pressure 13,6 times greater than that acting on water, but then the mass of a particle of mercury is 13,6 times heavier than that of an equally large particle of water.

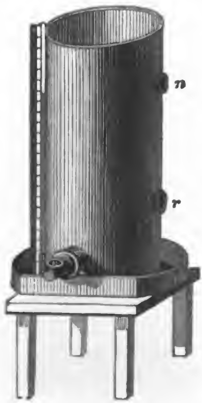
2. *The velocities of efflux are as the square roots of the heights of pressure.* The water must, therefore, flow with ten times greater velocity from an opening 100 centimetres below the level of the liquid, than from a depth of only one centimetre below the same level.

In order to determine the velocity of efflux, the simplest way is to observe a jet issuing vertically or horizontally from the vessel. We will first consider the vertically directed jet.

If the water spring forth from the opening o (Fig. 151) with the same velocity as if it were to fall from the level of the liquid in the vessel to the height of the opening o, the jet of water must rise again to the elevation of the liquid-level. We may easily show this by the help of the apparatus represented in Fig. 152, letting the water flow from the opening c; and we shall then find that the ascending jet of water does not attain to any thing like the height that might be ex-

FIG. 151.

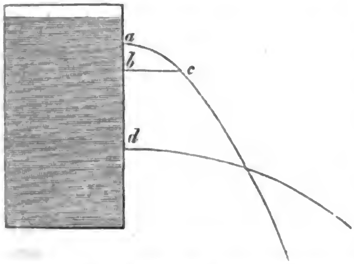
FIG. 152.



pected. The impediments to motion are, however, the sole cause of the water not attaining the height yielded by theory; the water falling back from the top exerts an essential influence in hindering the free ascent of the succeeding water; and consequently the jet rises the higher immediately the aperture of efflux is so turned, that the water flowing out may make a small angle with the vertical that is, that the ascending and descending jets may be close to each other. In this case, the jet may under favourable circumstances, that is where there is the smallest possible friction, attain an elevation 0,9 of the height of the pressure.

A stream of water flowing out in an horizontal direction describes a parabola, the form of which depends upon the velocity of its efflux. Supposing that the opening *a* (Fig. 153) were $0,1^m$ below the water level, the velocity of efflux would be according to the Toricellian law, $\sqrt{2.9,8.0,1} = 1,4^m$. If, therefore, a particle of water were at any moment to flow from the opening, it would in one second be $1,4^m$ from the vertical wall of the vessel, and $0,28^m$ in $\frac{2}{10}$ of a second. But in 0,2 of a second, the

FIG. 153.



water falls $0,196^m$ (we find this on substituting the value 0,2 for 1 in the equation $s = \frac{g}{2} t^2$); if now we measure the length $a\ b = 0,196^m$ downwards from the opening *a*, an horizontal line drawn from *b* towards the jet of water will intersect the latter at a distance of $0,28^m$. In making the experiment, the distance *b c* will be somewhat less than $0,28^m$ owing to the action of friction.

According to theory, the water should flow from a second opening *d* 40^{cm}, below the surface, with a velocity double that at *a*; if, therefore, we measure 196^{mm} from *d* downward, and then suppose a horizontal line drawn towards the jet it must intersect the latter at a distance of $0,56^m$.

The quantity of water issuing from an opening, in a given time, depends evidently upon the size of the opening, and the velocity of the efflux. If all the particles of water passed the opening with the velocity, corresponding according to the *Toricellian* law with the height of the pressure, the water flowing out in one second would

form a cylinder whose base would be equal to the opening, and its height equal to the distance described by a particle of water (owing to its velocity) in a second. This distance is, however, the velocity of the efflux itself, and therefore, $\sqrt{2gs}$, and designating the area of the opening by f, the quantity expelled in a second will be

$$m = f \cdot \sqrt{2gs}.$$

If we assume that the apertures m and n are circular, and that their diameter is 5^{mm}, the area of the opening $f = 19{,}625$ square millimetres, or 0,19625 square centimetres, if the height of the pressure be ten centimetres, the velocity of the efflux will be as we have already computed $1.4^{m} = 140^{cm}$, and therefore

$$m = 0{,}19625 \times 140 = 27{,}475 \text{ cubic-centimetres.}$$

In a minute, therefore, 1648,5 cubic-centimetres, or 148,5 cubic-centimetres, more than 1½ litres must flow out.

An aperture of equal size lying 40^{cm} below the water-level, must yield double as much in one minute; that is, 3 litres and 297 cubic-centimetres of water.

If we make the experiment, we find that the upper opening only yields about 1 litre and 55 cubic-centimetres, and the lower one 2 litres and 110 cubic-centimetres.

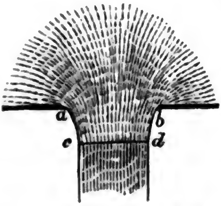
This difference, between the theoretical and the actually observed quantity of the discharge, proves incontrovertibly that all the particles of water do not pass the aperture with a velocity corresponding to the height of the pressure. In fact it is only those particles of water lying in the centre of the opening that have this velocity, while that of the particles flowing nearer to the edge of the opening, is much less considerable, as we shall see from the following observations.

In a wide vessel having a narrow opening, the whole liquid mass, with the exception of the parts in the vicinity of the aperture, may be regarded as at rest. The layers that successively flow out, do not begin their motion simultaneously, the foremost having attained the maximum of their velocity, whilst the most backward are beginning their motion. The consequence of this would be a breaking up of the successive layers if *vacua* could be formed; as this, however, cannot occur, the separate layers become more elongated while their diameter diminishes; but in the proportion that the diameter of these layers diminishes, other particles of water must flow on from the sides; as these, however, only begin later their motion at right angles to the opening, it is clear that they

ıust reach the opening with less velocity than the central lines f water.

Whilst the nucleus of the jet has a velocity corresponding to ıe height of the pressure at the moment of its leaving the aperture, is surrounded by lines of water, whose velocity diminishes in roportion as they approach the edge of the aperture: whence it ıllows, that the quantity flowing out must be less, than if all the articles left the opening with the velocity of the nucleus of the et.

FIG. 154.



The water flowing out is not perfectly cylindrical, but contracted at the opening as seen in Fig. 154, in consequence of the central lines of water at their passage through the opening having a greater velocity than the parts near the edges, and in consequence of the latter being possessed of a velocity directed towards the centre of the jet. At *c d* the liagonal section of the stream is about equal to two thirds of the ırea of the opening. In like manner the actual quantity of water expelled is about two thirds of the theoretical.

Influence of conducting tubes upon the quantity of liquid discharged.—If the efflux does not take place through openings made in a thin wall, but through short tubes, remarkable modifications occur, which we purpose considering.

If a conducting tube have exactly the form of the free jet from the opening to the part where the latter contracts, and exactly the length between these two points, it will exercise no influence upon the quantity of liquid discharged.

In cylindrical pipes, the water either pours freely out as from an opening of equal diameter, in which case no influence is exercised upon the quantity of liquid, or the water adheres to the walls of the pipes, so that the liquid fills the whole pipe, and flows forth in a stream having the diameter of the pipe; in this case the pipe considerably influences the quantity discharged. Whilst an opening in a thin wall yields theoretically 0.64 of liquid, we obtain by such a cylindrical conducting pipe of like diameter 84 p. c., provided the length of the pipe is equal to four times its diameter. The stream always adheres to the pipes at lower, while it is free at greater pressures. Where there is a medium pressure, it may be made free or adherent at pleasure; an inconsiderable

impediment will occasion adhesion, while a very slight touch is often sufficient to render the stream free.

A conical conducting pipe acts in case it discharges when full, in the same manner as a cylindrical pipe, excepting that it occasions an increased efflux.

The speed of the efflux is diminished in cylindrical or conical conducting pipes in the same proportion as the quantity of discharge is increased.

We must now examine how it happens that conducting pipes increase the quantity of liquid discharged, while on the contrary they diminish the velocity of the efflux.

The water suffers a contraction on entering the conducting pipe, in the same manner as if it were discharged from an opening in a thin wall, but besides this, as soon as the walls of the pipe are wetted, adhesion acts in such a manner on these walls that the conducting tubes become entirely filled, and the diagonal section of the stream thus increases, being at its exit from the pipe larger than at the place of contraction as may be seen at Fig 155. That such a contraction actually occurs in the tube is proved by this, that if we give the conducting tube the shape of a contracted stream as in Fig. 156, the efflux is precisely the same as if the conducting tube were cylindrical.

FIG. 155.

FIG. 156.

If the particles of water filling the whole section of the tube leave it with the same velocity with which they pass the most contracted part, a breaking up of the succeeding layers of water must necessarily occur. The separation of the particles of water, and consequently the formation of *vacua* is, however, hindered by the pressure of the air which accelerates the motion of the liquid while flowing into the tube, but retards its efflux from it. By atmospheric pressure, the particles of water flowing out are so much retarded that a full efflux is produced.

That the pressure of the air really has this effect is especially proved by the quantity of the discharge not being increased by putting on conducting pipes where water flows into a *vacuum*.

If we make a hole in the lateral wall of a conducting pipe, the air will be drawn in through this opening, and the stream will cease to be continuous.

If a bent tube x y, Fig. 155, whose lower end opens into a vessel of water, be inserted into the lateral wall, the water in the

tube $x\ y$ will be sucked up by the tendency manifested by the water to form a vacuum in the conducting pipe. This phenomenon proves likewise the influence exercised by the air in the above experiments. As a conical conducting pipe gives a larger discharge than one that is cylindrical, it must also draw up more liquid, that is, under otherwise similar conditions the column of water drawn into the tube $x\ y$ by a conical conducting pipe will rise to a greater height than in a cylindrical pipe.

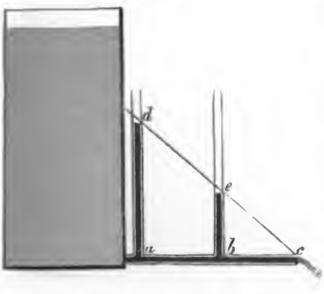
Lateral pressure of liquids in motion.—If water flow through pipes out of a reservoir, the lateral walls of the pipes would not have to support any pressure, if there were no resistance of friction to overcome, this, however, under some circumstances may be so considerable, that the greater part of the hydrostatic pressure is lost in overcoming this resistance, and proves of no avail in aiding the motion.

Instead of the plate with the opening *c* in Fig. 152, let us insert into the apparatus a cork, in which is a glass tube three feet in length, and give the tube a horizontal direction when the water at the end of the tube will then flow out much more slowly than if the efflux had occurred through the opening *c*.

If we apply several equally long tubes of different diameters to exhibit this experiment, we shall see how the velocity of the discharge diminishes with the narrowness of the tubes.

Supposing we find that the velocity of the efflux for one of these tubes is only half as great as we should expect from the amount of height of the pressure, then the one half of this pressure is necessary to overcome the friction, and the other half only is available for motion. If the water in the tube *a c*, (Fig. 157) were to move with a velocity corresponding to the height of the pressure in the reservoir, the walls of the tubes would have no pressure to support; but if the water in the reservoir produces in the tube a motion corresponding only to a part of the height of the pressure, the remainder must act upon the walls of the tubes as hydrostatic pressure. The pressure sustained by the walls is, however, not equal in all parts of the tube, being

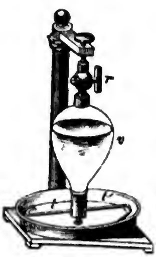
FIG. 157.



less the nearer it approaches the opening *c*. In many cases, the pressure to be supported by the walls of the tubes from within may be less than the pressure of air acting upon them from without; this is every where the case where the conditions are fulfilled in which the phenomenon of suction occurs.

Reaction created by the efflux of Liquids.—If we suppose a vessel filled with water, the whole will be at rest, as every lateral pressure is counteracted by a perfectly equal, but opposite one. But if we make an opening at any part of the wall from which the water may flow forth, the pressure will evidently be removed at this spot, whilst the portion of the wall diametrically opposite, and corresponding to it will be pressed upon as strongly as before. The pressure, therefore, on the wall of a vessel through which the opening has been made, is less than that acting on the opposite side, consequently the whole vessel must move in a direction opposed to the direction in which the stream of water flows out, if this motion be not hindered by friction or some other cause. This may be compared to the recoil of fire-arms. The reaction manifested on the escape of water may be shown by an apparatus known by the name of *Segner's Water-wheel.* It consists of a vessel *v* turning round a vertical axis, and having at its upper extremity a cock *r*, which need only be turned in order to put the apparatus into motion. By means of the reaction of the streams of water, issuing from the end of the horizontal and curved tubes *t* and *t'*, and at a tangent to the circle described by the end of the tubes, the apparatus receives a rapid rotatory motion.

FIG. 158.



Vertical Water-wheels.—If water continually flow from a more highly elevated to a lower spot, it may be applied as a moving force.

If during an unit of time, as a second, a mass of water whose weight is M flow, or fall from a height h, $M\,h$ is the quantity of motion, or the mechanical moment of this mass of water. In whatever way we may turn the motion of the water to another body, the effect can never exceed the mechanical moment of the fall, that is we can by means of the fall *at most* raise to an equal height, a weight equal to the mass of water falling from the same height in the same unit of time, or effect some other similar action. If, for instance, a mass of water of 800 lbs. fell from a height of

enty-four feet in one second, the absolute maximum of the effect this fall is 19200, that is, a result might be produced by this l, supposing all forces to come into action without there being y loss by friction or other resistance, which would be equal to e force necessary to raise a weight of 19200 lbs. in one second an elevation of one foot.

If we assume that a horse working with medium force and edium speed can raise a load of 100 lbs., four feet in one second, e absolute maximum of the effect of that fall might be compared, would be equal to a forty-eight horse-power. In what follows, will designate the absolute maximum of a fall by the letter E.

In order to avail ourselves of the mechanical moment of a water-ll, we generally make use of *water-wheels,* that is wheels, on the cumference of which the water acts by means of pressure or ipact.

Ordinary water-wheels turn in a vertical plane round an hori-ntal axis. We distinguish three main kinds of vertical water-heels, *under-shot, over-shot* and *middle-shot.*

In *under-shot* wheels the float-boards are at right angles with e circumference of the wheel. The lowest float-boards are im-ersed in the water, which flows with a velocity depending upon e height of the fall.

The flowing water sets the wheel in motion, and imparts to it velocity which may be greater or smaller according to circum-ances.

If the impact of the water is to impart to the wheel a velocity jual to that with which the water would flow if there were no heel, there must be no resistance opposed by the wheel to this otion, it must therefore not be loaded; or in this case there in be no mechanical action produced, and the effect will be ull.

On the other hand we might load the wheel so strongly by a ounterpoising weight, that the strike of the water would not npart any motion to it, the falling water exercising only a static ressure, and keeping the whole in equilibrium. In this case, the ffect is also null. From this consideration it follows that where ie wheel is to do any work, it must move with a velocity less than iat of the freely flowing water; theory and experience show that he most advantageous effect is produced, if the velocity of the heel be half as great as that corresponding to the height of the ill.

Hence it follows that only half of the mechanical moment of the fall comes into action in an ordinary under-shot wheel, while the water flows off with half the velocity with which it came on the wheel; the effect of such a wheel can, therefore, never exceed the value of $\frac{1}{2}E$. Even this effect cannot be practically obtained, as a part of the force is lost by the adhesion of the water to the walls of the channel, resistance of friction, &c. Carefully conducted experiments have yielded the value

$$e = 0{,}3\ E$$

for under-shot wheels moving in a channel, where no lateral efflux of the water could take place.

But in unconfined wheels, as those applied to ship-mills, where the water may escape laterally, the effect is still more remote from the absolute maximum. Under-shot wheels are applied where there is a considerable mass of water, but where the fall is of small elevation.

As the mechanical moment of the fall is turned to little account in the above described under-shot wheels where the water strikes the float-boards at right angles, *Poncelet* has constructed an under-shot wheel with curved float-boards, the effect of which approaches far nearer to the absolute maximum.

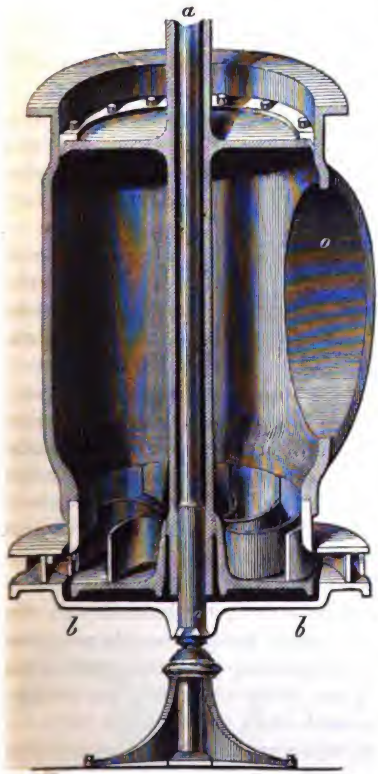
In order to have the water come upon the wheel without a sudden stroke, the float-board at the circumference of the wheel must correspond with the direction of the tangent; but if they were so constructed, the water would be hindered in falling from the wheel; besides which the water must not expend all its velocity on the wheel, since in that case, it would have none left for flowing off. Thus a certain loss of power, independently of the natural impediments, is unavoidable even in *Poncelet's* wheel.

Wheels with curved float-boards are computed to yield an effect equal to two-thirds or even three-fourths of the absolute maximum. This result is explained in *Poncelet's* wheels by the water losing its velocity as it ascends the curved float-boards, and yielding it almost entirely to the wheel.

The over-shot Wheel is applied where there is a high fall of an inconsiderable quantity of water, as in small mountain streams. The water in running down upon it fills the cells on one side of the wheel, which is turned by this very addition of weight. Near the lower part of the wheel the water again flows out of the cells. There is also a portion of the mechanical moment lost in over-shot wheels, because the cells cannot keep the water down to the lowest

point of the wheel, but begin sooner to let it flow out. A well constructed over-shot wheel ought to produce an effect amounting to 75 per cent of the absolute maximum, provided that it turn slowly, for rapid turning the water does not remain in an horizontal position in the cells, in consequence of the centrifugal force, but rises exteriorly, so that it falls sooner from the cells.

FIG. 159.



The middle-shot wheel is a kind of medium between the over, and the under-shot wheel.

Horizontal Water-wheels.—Earlier attempts were made to construct water-wheels, but it is only recently that they have been practically applied by *Fourneyron.* The horizontal wheels he invented are known by the name of turbines.

Fig. 159 represents one of these constructed for a high fall of water.

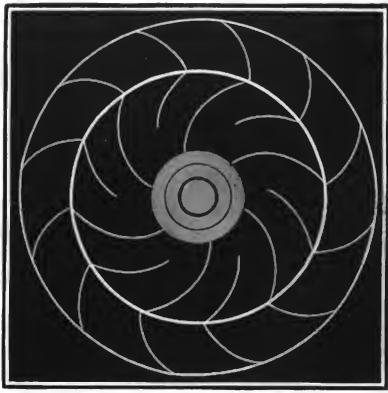
The whole mass of the falling water is collected in a wide cast iron tube, connected with a cast iron reservoir by the opening *o*. A hollow tube passes through the middle of the reservoir connecting the upper lid with the bottom. This horizontal bottom does not, however, touch the vertical walls of the vessel, there being between it and the lateral walls an annular interval from which the water flows in a horizontal direction.

This water thus streaming out sets the horizontal wheel with its vertical spokes in motion; *a a* is the vertical axis, round which the wheel turns, passing through the shell connecting the bottom and

the cover of the reservoir. To this axis the plate *b b* is fastened, opposite to the opening of the reservoir bearing the rim of the wheel with the float-boards.

The float-boards are curved as seen in the sectional view in Fig. 160; in order, however, to make the water strike the float-boards of the wheel in the most advantageous direction, conducting curves made of tin are fastened to the plate of the reservoir to give a determined direction to the water.

FIG. 160.



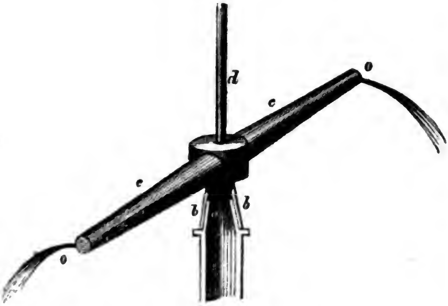
It would detain us too long were we to enter into a particular description of the most advantageous curvature for float-boards, and conducting curves. *Furneyron's* turbines, if well constructed, ought to produce an effect, amounting to 75 p. c. of the absolute maximum. *Gadiat* has simplified them by leaving out the conducting curves, and thus lost 5 p. c. more of the absolute maximum effect, so that his turbines still yield 70 p. c.

Turbines are particularly useful for high falls which do not admit of the use of vertical wheels.

Attempts have been made to enlarge upon the *Segner* water-wheel, in order to work machinery with it, but hitherto with very little effect; a very small motive power being invariably produced. The reason of the want of success attending these attempts did not arise from the active moving power being too small, but because the lower of the two pivots around which the apparatus turns has to bear the whole weight of a large mass of water, in consequence of which there is a disproportionally large amount of resistance from friction to be overcome.

This objection has been ingeniously set aside by *Althans* of Sayn, who has made such an alteration in the apparatus, that the water enters the horizontal arms from below, and not from above. The most essential part of arrangement is shown in Fig. 161. The

FIG. 161.

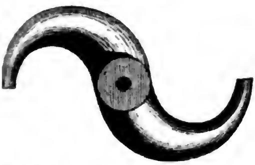


reservoir is formed by a cast iron conducting pipe, which is curved horizontally below, and ends in a vertically rising piece of tube *a*. From the opening at *a*, the water flows into the neck *b* attached to the end of the tube *a* in such a manner that it can turn round it as round a pivot. The water passes through the neck *b* into the horizontal arm *c*, and flows out of the openings at *o*. The motion of the wheel is transmitted by the axis *d*.

The friction to be overcome by such a wheel in revolving round the pivot *a*, must be very inconsiderable, for the weight of the wheel with all that is fastened to it is almost entirely supported by the pressure of the column of water, so that the pivot *a* has scarcely any pressure to sustain.

In the apparatus seen at Fig. 161, a large portion of the mechanical moment of the fall must be lost from reasons similar to those affecting the under-shot wheel with flat float-boards, for if the water imparts all its velocity to the wheel, and falls from the openings without any velocity, and if, therefore, the wheel rotate with a rapidity corresponding to the operation of the fall, the pressure backwards, and consequently the mechanical effect will be null also. The water must still retain a portion of its velocity of motion. Much may be gained here by curving the arms, somewhat in the manner represented in Fig. 162. The water imparts its velocity gradually to the wheel, flowing through the tube, and pressing against the curved walls, so that it falls at the opening almost devoid of all rapidity.

FIG. 162.



In Scotland such turbines of reaction are much used, on which account they are often called Scotch turbines.

Water-column Machines.—In these machines the acting column

of water, pressing upon a piston that moves in a cylinder, imparts to it a forward and backward motion which is farther transmitted by the piston.

Water-column machines are generally applied for the purpose of raising water to a considerable height. In this manner, for instance, the salt spring at *Reichenhall* in *Upper Bavaria* is conducted by a circuitous course about one hundred and twenty miles to *Rosenheim,* and other intermediate places for the purpose of being boiled. On this road there are nine of these water-column machines, constructed by *Reichenbach,* to raise the springs over the mountainous heights. Although all these machines depend upon the same principle, their mode of action is in many respects different; we will here consider with attention one of nine of those most simply arranged, that at *Nesselgrabe.*

The pipe *A* leads the impelling water to the machine, it enters alternately into the upper and lower part of the cylinder *B,* where it drives the piston *C* alternately up and down.

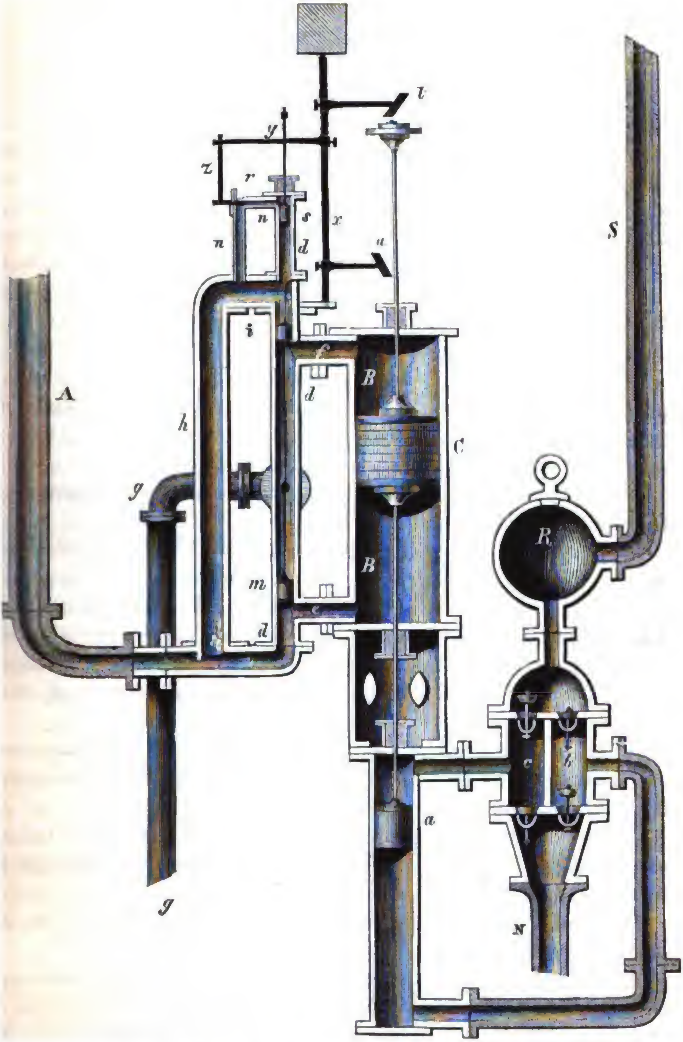
In order to produce this alternation, on the entrance of the water, an arrangement has been applied precisely similar to the contrivance used for governing steam-engines. Three connected pistons move in the cylinder *d,* the two lower ones are alike, while the upper one has a smaller diameter.

In the position of the piston as represented in the drawing, the impelling water passes through the pipe *e* into the large cylinder, and raises the piston *C.* The water above *C* flows through the pipe *f* into the pipe *d,* and from thence passes away through the pipe *g.*

When the piston *C* is raised, the pistons must be so displaced in the tube *d,* that now the impelling water may enter the large cylinder. This is effected by the pistons descending so far in *d,* that the piston *i* stands below the tube *f,* and the piston *m* below *e;* then the impelling water passes from the tube *A* through *h* and *f* into the upper part of the cylinder *B,* drives down the piston *C,* whilst the water below *C* passes through *e* into the tube *d,* flowing off through the tube *g.*

The elevation and depression of the pistons in the tube *d* is effected in the following manner. The tube *h* is connected by the tube *n* with the upper part of the tube *d:* at the joint of the tube *n,* a cock *r* is applied, which according to its position at one time connects the upper part of the tube *d* with *h,* and at another cuts off this connection and puts the upper part of the tube *d* in communication with

FIG. 163.



he external air. If now we suppose the cock to be so placed that he impelling water can enter from *h* by means of this cock into he upper part of *d*, the piston *s* will be pressed upon above and

below by an equal power of water; besides this, the water presses above on the piston *i*, below on the piston *m;* the pistons, therefore, are exposed to equal water-pressure from above and below, and descend by their own weight.

When the pistons are to rise, the cock *r* is so arranged that the communication between *h* and the upper part of *d* is interrupted. Now no pressure of water acts upon *s*, the water above *s* escaping from the machine by the cock. The water-pressure from above against *i* is counteracted by the pressure from below against *m*, and the pressure of the water from below *s*, to which there is no counter pressure, raises the pistons.

The turning of the cock is effected by the machine itself. At the upper end of the rod fastened to the piston *C*, a round disc is applied, which strikes against the oblique surface *t* on the rising of the piston, and against the oblique surface *u* on its sinking, pushing them sideways, and thus causing a revolution about the axis *x*. The arm *y* is fastened to this axis, and the arm *z*, by its rotation, causes the cock to turn.

Let us now further consider how the motion of the piston *c* is transmitted and applied to the other parts.

The piston *a* is connected with the piston *C* by means of a rod passing through a stuffing box, and has a much smaller diameter than *C*, the elevation and depression of the piston, cause, therefore, a similar motion in the piston *a;* but when *a* rises, a rarefaction of air takes place in the chamber *b*, the lower valve opens, and water is raised through the suction pipe *N* into the chamber *b*. By the rising of the piston *a*, water is pressed into the chamber *c*, the lower valve closes, the upper one opens, and the water is thus raised through the piston into the reservoir *R*, and from this into the ascending pipe *S*.

On the descent of the piston, the valves which were open, close, and *vice versa;* water is sucked up into the chamber *c*, and raised from *b* into the reservoir, and the ascending pipe.

If the diameter of the piston, *C*, be two, three or four times greater than that of the piston *a*, we may raise a column of water (disregarding friction and other impediments) two, three, or four times as high as the height of the impelling water.

In the water-column machines we have been considering the height of the impelling water is 140 feet, it raises the brine to a height of 346 feet, but this column of salt water corresponds to a column of fresh water of 397 feet; the diameter of the piston *C* is 20½,

that of the piston *a* 10 inches, the larger one having almost four times as great a diameter. The reason of the height of the raised column of water not being four times greater than the height of the impelling water that is, not 560 feet, is owing to a considerable force being necessary to overcome friction and other resistances. This machine yields, therefore, about 70 per cent. of the absolute maximum, for 397 is to 560 nearly as 70 to 100.

The water-column machine at *Ilsang,* also between *Reichenhall* and *Rosenheim,* which is somewhat differently constructed, raises the spring to an elevation of 1218 feet, equal to the raising of a column of fresh water to a height of 1460 feet. The diameter of the larger piston is 25 feet 8 lines, that of the smaller, 11 feet 3¼ lines.

Great difficulties present themselves in converting the backward and forward motion of the piston in these water-column machines into an uniformly circular motion, as seen in steam engines, owing to the water not being elastic like steam. But *Reichenbach* has ingeniously met this difficulty in the construction of a small machine at *Toscana,* by applying a guiding or directing piston; we cannot, however, here enter further into the consideration of this subject.

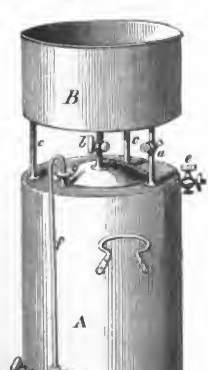
CHAPTER III.

MOTION OF GASES.

If a gas be enclosed in a vessel having any kind of opening, it will escape through the opening as soon as the gas in the vessel is more strongly compressed than the air in the space communicating with the aperture. The laws of the passage of gases through openings in thin walls, and through conducting pipes are analogous to those bodies of liquid with which we have become acquainted. The term gasometer is applied to an apparatus serving to maintain a constant discharge of gas.

In chemical laboratories, the form most commonly used for gasometers is represented at Fig. 164. *A* is a cylinder of lacquered tin, about 16 to 18 inches in height, and 10 to 12 inches in diameter, having its upper cover vaulted. On this cover stands a second cylinder *B*, open at the top, resting upon three supports, and only $\frac{1}{3}$ of the height of the lower one. The upper cylinder is connected with the lower by means of two tubes, of which the one *h* is exactly in the middle of the cover. This must not quite enter the lower cylinder. A second connecting tube *a* reaches almost to the bottom of the lower cylinder. In each of the tubes there is a cock, by means of which we may at pleasure establish or interrupt the communication of the two cylinders. At *e* there is a short horizontal tube, which may also be closed by a cock, and to which a screw is attached, in order to admit of other pipes and openings being connected with it. Near

FIG. 164.

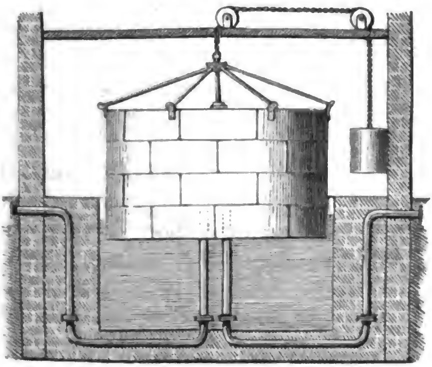


the bottom of the lower cylinder, there is an opening at *d* directed upwards, that may be closed by means of a screw or cock. If we wish to fill the lower cylinder with a gas, we first fill it with water in the following manner. The opening at *d* must be closed, the three cocks opened, and then water poured into the upper vessel. The water flows into the lower cylinder, and as soon as this is filled to *e*, we close the cock. The remainder of the air, still in the cylinder, escapes through the tube *h*. When the lower cylinder is thus filled with water, the cocks of the connecting pipes are closed, and the screw or cork at *d* taken off. Water cannot flow from hence because no bubbles of air are able to enter. But if we insert a gas conducting tube at *d*, the water will flow out in its vicinity, whilst bubbles of gas continually ascend from it into the upper part of the receiver. In this manner, the lower cylinder fills itself more and more with gas. We may see how far the cylinder is filled with gas by the glass tube *f*, which is so connected above and below with the vessel, that the water stands as high in it as in the cylinder.

When the whole reservoir is filled with gas, the opening at *d* is closed, and the cock of the connecting tube *a* is opened. As soon as the cock *e* is opened, the gas escapes with a rapidity corresponding to the pressure of the column of water in the tube *a*.

Large gasometers used for gas illumination are constructed on a different principle, a cylinder closed at the top dips into a large reservoir filled with water, (Fig. 165). This cylinder is made of tin, is ten metres in diameter, contains 100 cubic metres of gas, and weighs as we will assume 10,000 kilgr. It does not sink in the water, in consequence of its being filled with gas; but its whole weight presses upon this gas with a force greater than the pressure of the atmosphere. According to our assumption, this excess of pressure amounts to

FIG. 165.

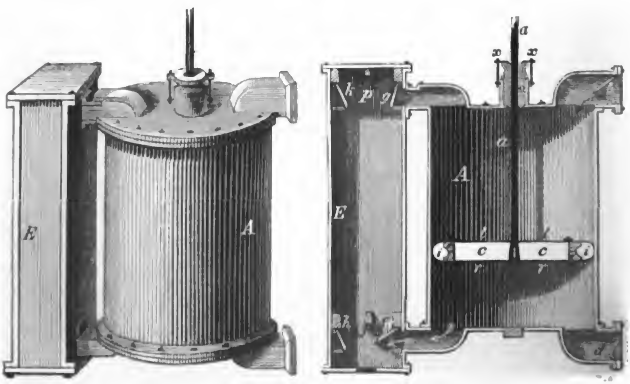


10,000 kilogr. upon a circular area of ten metres in diameter, which is about equal to the pressure of a column of water of 13 centimetres; the water must, therefore, stand 13 centimetres higher without than within the cylinder.

Ascending from below, a pipe passes into the cylinder, having its upper open end above the level of the water; this pipe separates into a number of narrower ones, leading to the mouths of the separate gas pipes, from which the gas pours out with a velocity corresponding to the pressure in the gasometer. This velocity is constant, because the gasometer, even though it sank more deeply into the water, only loses a little of its weight, as it is only the wall of the gasometer that is here to be taken into account. The pressure upon the gas is modified and regulated by a counter weight. In order to fill the gasometer, the cock in the distributing pipe is closed, while the cock of another pipe is opened, connecting the interior of the gasometer with the apparatus in which the gas is prepared.

Blowers or blowing machines of various modes of construction are used in forges. The most applicable kind, and that now generally used is the cylindrical blower as represented at Fig. 166. In a well

FIG. 166.



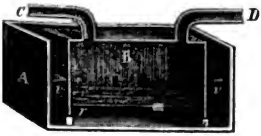
bored cast iron cylinder *A*, in which an air-tight piston *C* may be moved up and down, the piston-rod *a* passes air-tight through the stuffing box in the centre of the upper cover. The upper and lower parts of the cylinder communicate at the opening *b* and *d*, with the external air; while the openings at *g* and *f* convert the cylinder

vith a square box E. At b and d are valves opening inwards, at ι and f valves opening outwards. When the piston descends, the 'alve at d closes, while that at f opens, all the air being driven 'rom the lower part of the cylinder into the space E. But in the nean while the valve at g is closed, while the air presses through he valve at b from without into the upper part of the cylinder. When the piston again rises, b closes, and all the air forced in by he descent of the piston is carried through the opening at g into he box b, while f is closed, and the under part of the cylinder is ıgain filled with air passing through the open valve d. The air :ompressed in E passes to the space occupied by the fire through ı tube applied at m.

The velocity of the piston is greatest when it passes the middle of the cylinder, it diminishes the more the piston approaches the ıpper or lower limit of its course. Hence it follows that the blast rielded by such a cylinder does not pass out in an uniform manner ıt m. As, however, an uniform current is necessary for most ımelting processes, care must be taken to regulate it. This is ffected either by applying three cylinders to the same air box E, whose pistons do not simultaneously pass the middle point of their :ourse; or by suffering the air to enter from E into a receiver, whose area is very large in proportion to the volume of the :ylinder. The larger this air receiver is, which is termed the *egulator*, the less influence will the irregularity of the movements of he piston exercise upon the regularity of the current of air passing ›ut of the regulator.

As regulator for a blower there is used either an air-tight ›alloon of sheet iron, whose contents are from forty to fifty times ıs large as that of the cylinder, or else the water regulator repre-ented at Fig. 167, which is quite identical in its nature with the gasometer, as used for gas lighting.

FIG. 167.



In the box B consisting of iron plates secured together so as not to admit of the entrance of air, and whose contents far exceed those of the cylinder, the air pours through the tube D from the cylinder, escaping through he tube C. The air in the box B is enclosed below by water, whose level r r necessarily stands lower within the box than the surface v v without.

On the difference of the heights of the levels of the water

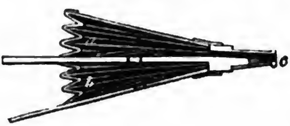
depend the degree of compression of the air at *B*, and the velocity of the discharge through the tube *c*.

In order to determine the pressure of the air in the different parts of the blowing apparatus, a *manometer* is used, which, when applied to this especial purpose, is termed a wind-measurer. A section of a very well constructed instrument of this kind is represented at Fig. 168. An hermetically closed block-tin box is partly filled with water. A tube *a* passes through the bottom of the box, having a screw below, by which it may be secured to the blower. The apparatus communicates by means of this tube with the upper part of the tin box, where the air is consequently as strongly compressed as in that portion of the apparatus to which the wind-measure is screwed. A graduated glass tube *b* is connected with the lower part of the tin box. Water is poured through an opening in the cover of the box, until the water in the tube stands exactly at zero of the graduated tube, when the opening is closed by a cork stopper. As soon as the air is compressed in the upper part of the tin box, the water rises in the tube without any marked sinking of the level of the water within the box; the rising of the column of water above the zero point of the glass tube indicates, therefore, the pressure sustained by the air within the apparatus. By means of the cock, the communication between the tin box and the glass tube may be interrupted at pleasure.

FIG. 168.

The most simple form of the *bellows* is sufficiently well known, but with bellows thus constructed, we are unable to engender a continuous current of air, such as is necessary in forges and in chemical laboratories. For such purposes compound bellows are used, as represented at Fig. 169. If the upper division *a* of such bellows be filled with air, compressed by the weight resting upon the upper cover, it can only escape by the opening at *c*, for the value between *a* and *b* closes as soon as the air becomes more strongly compressed in *a* than in *b*. When the lower surface

FIG. 169.



of the space b rises, the air is compressed in b, raises the valve leading to a, and presses into the upper space. On the descent of the lowest side, the valve between a and b closes; the valve communicating from b with the air opens, b is again filled with air, which is again forced into the upper space. It will be readily understood that the pouring forth of air from a through the opening c is not interrupted while b supplies itself with air.

Laws of the flow of Gases.—The same laws apply to the velocity of the efflux of gases that we have given for liquids, that is to say the velocity of the efflux is

$$c = \sqrt{2gs},$$

if s represent the height of pressure. Here, however, s is a magnitude not directly given by observation as for liquid bodies; s designates the height of the column of fluid, whose pressure occasions the discharge, and which is of the same nature and density as that flowing out. Gases contained in a vessel are not, however, at any time compressed by a column of air of equal density, and well defined height, for even if the gas were only compressed by the pressure of the atmosphere, the column of air producing this result is neither of uniform density, nor measurable height. Therefore, even in this case, s cannot be directly obtained from observation. The pressure driving the air from a reservoir is, however, usually measured by the height of a column of water, or mercury, observed by means of a manometer. The valve of s which must be substituted in the above formula for the velocity of the discharge, may therefore, always be computed from the circumstances observed.

The simplest case that can be adduced is that of air being forced into a *vacuum* by atmospheric pressure. The medium atmospheric pressure equipoises a column of water 32 feet in height, or 10,4 metres. But the density of the air having to sustain this medium pressure is 770 times less than that of water; a column of air, therefore, having this density throughout, must have a height of $770 \times 10{,}4 = 8008$ metres to counterpoise the pressure of the atmosphere. For this case, therefore, $s = 8008^m$ and consequently $c = \sqrt{2 \times 9{,}8 \,.\, 8008} = 396^m$.

If the air pour into a vacuum from a reservoir in which it has only been compressed by the pressure of half an atmosphere, the velocity of the discharge will be precisely as great as in the last

case, namely 396^m. The reason of this is easily understood, for although the discharge is produced here by a pressure of only half the quantity in the former case, the air flowing out has here only half the density. Besides the velocity with which the air rushes into a vacuum is always the same, whilst the pressure on which this velocity depends may be very various.

If the discharge be directed towards a space already containing air, although of inconsiderable tension, the tendency to escape will necessarily depend upon the difference of the two tensions. If we designate this difference by a column of air of the height H, and of the density of air more compressed, the velocity of the discharge will be

$$c = \sqrt{2\,g\,H}.$$

We will endeavour to determine the value of H in a case where air more compressed is discharged into atmospheric air of the ordinary tension. Let the compression of the air in the reservoir be measured by a column of water, whose height we will designate by h. This height h gives the difference between the tension of the inner and the outer air, and we have only to determine what must be the height of a column of air of the density of the air in the reservoir, to enable it to counterpoise a column of water of the height h.

If we had to do with air of medium atmospheric pressure, we might substitute a column of air of the height of $770\,h$ for the column of water of the height h. In order, however, to equipoise the same column of water we want a column of air of smaller height if the air be denser, the requisite height bearing an inverse relation to the density of the air.

Atmospheric air of average pressure which is 770 times lighter than water, is likewise compressed by a column of water of 32 feet or 10,4 metres, whose height may be designated by b, whilst the air in the reservoir has to sustain the pressure of a column of water of the height $b' + h$, if b' designate the height of a column of water corresponding exactly to the then heighth of the barometer. The density of air of average pressure is, therefore, to the density of the air in the reservoir as $b : b' + h$, the air in the reservoir is, therefore, $\frac{b' + h}{b}$ times as dense as the air of average atmospheric pressure, instead, therefore, of a column of air of the height of $770\,h$ of

his more rarefied air, we must substitute a column of the height $\frac{770 \,.\, h \,.\, b}{b'+h}$ of this more rarefied air, and this value of $\frac{770 \,.\, h \,.\, b}{b'+h}$ we must put in the above equation in the place of H: for a column of air of the height $\frac{770\, b \,.\, h}{b'+h}$, and the density of the air in the reservoir would entirely counterpoise the column of water of the height h. The velocity of the efflux is, therefore, in this case

$$c = \sqrt{2g \frac{770\, b \,.\, h}{b'+h}}.$$

We should obtain the quantity discharged in a second if we multiplied the area of the opening by this value of c, provided that the particles of air flowed out in every part of the diagonal section with equal velocity. The quantity discharged in t seconds would be according to this

$$M = f \,.\, t \sqrt{2g \frac{770\, b \,.\, h}{b'+h}}.$$

Experience, however, shows, as we have seen in liquid bodies, that the actual quantity discharged is far smaller than what is yielded by theory, and we must multiply the theoretical quantity by a definite factor μ in order to obtain the actual amount.

For water, this factor is 0,64, and is almost entirely independent of the height of the pressure, increasing only very inconsiderably when the height of the pressure diminishes. For gases, however, the value of μ is very variable. According to *Schmidt*, who was the first to direct particular attention to this subject, μ is equal to 0,52 at a height of pressure of three feet (water); while *d'Aubuisson's* experiments yield the value of μ as equal to 0,65 at heights of pressure, varying between from 0,1 to 0,5 of a foot.

The difference between the theoretical and actual quantity discharged depends upon causes analogous to those affecting liquid bodies, and we may, therefore, conclude that a *contractio venæ* must occur, although it does not admit of direct observation.

Cylindrical as well as conical conducting pipes, whether the wide opening be turned inwards or outwards, increase the quantity of the gas discharged.

Lateral pressure of Gases in the flowing out. — When air

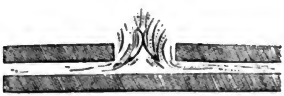
moves through conducting tubes, there is a resistance to be overcome from friction, for which a portion of the tension of the compressed gas must be employed, and thus be lost to the motion.

The pressure sustained by the walls of the tube from the tension of the air passing through, diminishes in proportion as it approaches its mouth, as we may see by applying manometers to different parts of the tube. This is quite analogous to the phenomena observed in the motion of liquids passing through conducting tubes.

The phenomenon of suction takes place in the motion of gases precisely in the same manner as in the efflux of liquids. If we make an opening of one or two inches in diameter in the bottom of a vessel containing compressed air, the air will escape with great force. If we connect a disc of wood or metal, seven or eight inches in diameter with the opening, it will not be pushed off after the first resistance has been overcome, it will oscillate quickly, approaching and retreating from the opening within very short intervals. The air in the mean time will escape with much noise between the disc and the wall. On attempting to remove the disc, we must use as much force as if it were cemented fast to the wall.

This phenomenon is explained in the following manner: the stream of air leaving the opening must spread itself in a thin layer between the disc and the wall, (Fig. 170). The density remaining unchanged, it must extend in proportion as it approaches the edge of the disc; it finds itself consequently in the same case as a liquid stream which is to fill up the constantly increasing diagonal section of a conical conducting pipe. Between the disc and wall, a *vacuum* is formed, in consequence of which the atmospheric air pressing from below against the disc forces it against the wall.

FIG. 170.



We may make this experiment on a small scale by blowing air with the mouth through a tube at the end of which is a flat smooth disc. If we put a card while blowing to the opening of the tube in the middle of the disc, we shall observe the above mentioned phenomenon.

Faraday has suggested the most simple mode of making this experiment. On laying the fingers of the open hand closely

together, a series of intervals will still remain from joint to joint; whilst the hand is held thus horizontally, with the palm turned downwards, we must apply the lips to the space intervening between the index and middle finger (near the roots), and blow with as much force as possible. If then a piece of paper, of three or four square inches be applied to the opening, through which this current of air passes, it will neither be blown away by this current, nor will it fall by its weight until we cease blowing.

SECTION IV.

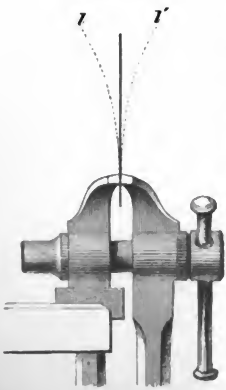
ACOUSTICS.

CHAPTER I.

LAWS OF THE MOTION OF WAVES IN GENERAL, AND ESPECIALLY OF WAVES OF SOUND.

Vibratory Motion.—If a pendulum be brought out of its position of equilibrium, and then left to itself, it will in the first place be carried back to a state of equilibrium by its gravity, but having returned to that point, it cannot remain at rest, because it reaches it with a velocity, that drives it out of its position of equilibrium; and hence the pendulum makes a number of oscillations, the laws of which we have already mentioned.

FIG. 171.



The mutual position of the particles remains unchanged in the motion of the pendulum. If, however, the relative position of the particles of a body be disturbed by any external cause, and if any forces be present, tending to restore the original state of equilibrium, they will also take up an oscillatory motion, which differs essentially from the motion of the pendulum by the mutual position of the particles changing every moment; we have here, therefore, to consider not only the oscillatory motion of an individual particle, but also the changes in the relative positions of the particles. The oscillatory movement of the indi-

vidual parts of a body may be of such a kind that all particles simultaneously come into motion, simultaneously pass the point of equilibrium, simultaneously reach the maximum of their oscillation, and simultaneously begin their retrograde motion. Such are the vibrations of a steel bar fastened at one end, Fig. 171, and of a cord extended between two fixed points (Fig. 172). Such vibrations are termed by *Weber*, "standing vibrations."

FIG. 172.

If the motions of the individual parts are of such a kind that vibratory motion proceeds from one particle to another, so that each makes the same oscillations as the preceding one, with the sole exception of the motion beginning later, we have *progressive vibrations*. By progressive vibrations, waves are formed. The motion, *the advance of the wave*, is to be regarded as essentially distinct from the oscillations of individual parts.

Examples of wave-motion are afforded by a quiet surface of water, on which we drop a stone; by a long tense line, near one end of which we strike with a sharp blow, the waves of sound in the air, &c., we will consider these various wave-motions more particularly.

The vibratory motions may be greater or smaller, according to the cause of the disturbance of the equilibrium, and the nature of the force, striving to restore the particles to their former condition of equilibrium; so that the external form of the body may in consequence suffer either well-marked or inconsiderable changes; the vibrations may be slower or faster; they may be so slow as to enable us to follow them with the eye, and count the several oscillations; while on the other hand they may be so fast as no longer to admit of being distinguished.

If the vibratory motion of a body exceed a certain degree of velocity, its combined effect may produce a certain impression by creating undulatory motions in the surrounding media, by means of which they are conveyed to peculiarly adapted organs of sense, occasioning to these latter a characteristic sensation.

Thus vibrations whose rapidity lies within certain limits, which we purpose speaking of more fully, occasion waves in the air, or in other elastic media, which consisting in alternate condensations and rarefactions are conveyed to the ear, and received by that organ as *sounds*.

Incomparably more rapid vibrations of the particles of a body

conveyed to the eye produce the impression of light by means of the undulatory motion of a peculiarly elastic fluid, which we term ether.

As the vibrations of sound as well as those of light are transmitted by undulatory motions, we will at once proceed to consider the most important laws connected therewith, beginning with water waves, as in them is incorporated the idea of a wave, and because a right comprehension of these will help to elucidate other undulatory motions, as for instance, sound-waves, which furnish especially interesting matter of consideration.

Water-waves.—If we throw a stone into the water, circular waves will be formed, spreading themselves from a centre (the spot where the stone fell) in all directions with uniform velocity when unopposed by any impediment. The waves consist of alternate elevations and depressions succeeding each other pretty quickly, and continuing to spread outward from the centre.

When a wave elevation proceeds outward, the individual particles of water do not share in this advancing motion, for we see when a piece of wood swims on the water, that it is alternately raised and lowered as the wave elevations and depressions uniformly glide away from under it.

The force by which the water-waves are propagated is gravity, for if from any cause an elevation or a depression be produced on the horizontal surface of the water, the gravity of the separate particles of water will endeavour to restore the disturbed horizontal plane, by which means an oscillatory motion is produced, which by degrees is propagated from one particle to another.

As soon as regular waves have been formed, the separate particles of water on the surface describe during the advance of the wave curves returning into themselves, which in cases of extreme regularity are circles, while in cases where the front of the wave elevation is not equal to the succeeding one, the individual particles of water describe curves which are not closed, and such as we have represented at Figs. 173 and 174.

FIG. 173.

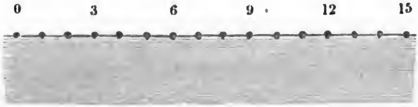
FIG. 174.

Let us now consider somewhat more attentively, the connection between the motion of the individual particles of water and the propagation of the wave.

Let us assume that a regular undulatory motion, advancing from left to right, spread itself to the particle of water 0 in Fig. 175, obliging it to describe a circular course. Now while the particle 0

completes, for the first time, its circular course, motion is propagated to a certain distance. Let the particle marked 12 be

FIG. 175.



the one to which the vibratory motion is propagated from 0, while 0 performs its revolution; then will 12 begin its first revolution at the moment that 0 enters upon its second.

If we now suppose the circumference of the circle described by the particle 0 to be divided into 12 equal parts as well as the space intervening between 0 and 12, the undulatory motion in the direction from 0 towards 12 will always advance one division further, whilst the particle 0 describes $\frac{1}{12}$th of its circular course.

While the particle 0 describes the first 12th part of its course, the undulatory motion extends to 1; and while 0 is passing over the first quarter of its course, the same motion is transmitted to 3.

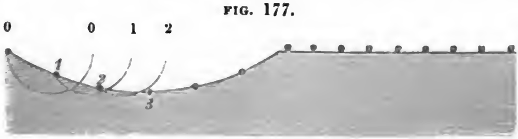
Fig. 176 represents the moment in which the particle 0 has

FIG. 176.

traversed the quarter or $\frac{3}{12}$th of the circle; the particle 1 has at that moment passed over $\frac{2}{12}$ths; the particle 2 $\frac{1}{12}$th; while the particle 3 is not yet displaced from its position of equilibrium.

Fig. 177 shows the moment in which the particle 0 has traversed

FIG. 177.



half its course; the particle 1 $\frac{5}{12}$ths; the particle 2 $\frac{4}{12}$ths; and the particle 3 $\frac{3}{12}$ths of their course; while the particles 4 and 5 are in

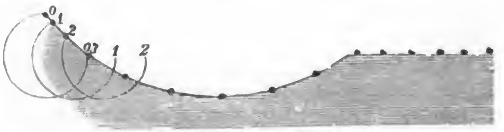
the same position as the particles 1 and 2 of the former figure. The particle 6, although not removed from its equilibrium, is about to begin its motion.

The particle 3 has reached its lowest point; here is the centre of a wave-depression.

If now $\frac{1}{12}$th of the time be necessary for a particle to complete its circuit be passed, the particle 3 will have come into such a position with reference to its original place, as is now the case with the particle 2; and the particle 4 will have reached its lowest position, being $\frac{1}{4}$ of the circle removed from its position of equilibrium; the wave-depression has, therefore, advanced from 3 to 4 in this interval of time.

Fig. 178 represents the moment in which the particle 0, having

FIG. 178.



traversed $\frac{3}{4}$th of its course, has reached the highest point of its circuit; here, therefore, is the summit of a wave-elevation. The particle 1 has traversed $\frac{8}{12}$ths; the particle 2 $\frac{7}{12}$ths; and 3 $\frac{6}{12}$ths of its course; the particles 4, 5, 6, 7, 8, are in the same position as 1, 2, 3, 4 and 5 of the former figure. From the moment represented in Fig. 177 to the moment shown in Fig. 178, the wave-depression has moved from 3 to 6.

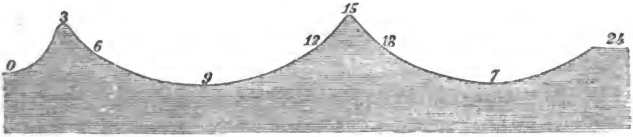
Whilst the particle 0 is traversing the last quarter of its course, the wave-elevation advances from 0 to 3, and the depression from 6 to 9; while at the same moment that 0 has ended its course for the first time, and is entering upon a second circuit, the particle 12 begins its course for the first time.

This moment is represented in Fig. 179, which needs no further explanation.

FIG. 179.

Fig. 180 represents the moment in which 0 has traversed its

FIG. 180.



course a second time; at this time 12 will have made its first circuit; motion been transmitted to 24, a wave-elevation is seen at 3, another at 15; one wave-depression at 9, and another at 21.

If the undulatory motion continue uninterrupted, the individual particles of water will likewise pursue their circuits; the wave-elevations as well as the wave depressions advancing uniformly from left to right, while one particle after the other reaches the highest and lowest point of its circuit.

Thus the wave-elevations and depressions advance owing to the same circular motion being imparted to all the particles of water, each entering upon that motion successively.

The distance between two adjacent particles in similar conditions of vibration, is called *the length of a wave*; as the distance between 0 and 12, and between 12 and 24, these particles beginning their oscillation simultaneously, and reaching simultaneously their highest and lowest points. According to this the distance from the summit of one elevation to the next, as from 3 to 15 in our figure, or from the middle of one depression to the middle of the next, as from 9 to 21 constitutes likewise *the length of a wave.*

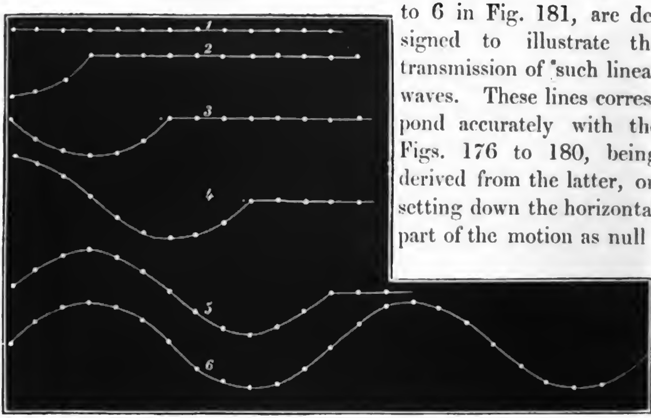
Those particles that are removed ½ of the length of a wave from each other, as 0 and 6, 3 and 9, 9 and 15, are always in opposite conditions of vibration. The particle 9, for instance, forms the lowest point of a depression; 3 and 15, on the contrary, the summit of wave-elevations. The particles 0 and 6 are certainly both in their position of equilibrium, but the motion from 0 is directed downward, while that from 6 is directed upward.

The time required by a particle to complete an oscillation is termed the time of an oscillation; whilst a particle is completing an oscillation, the wave advances a length.

Linear-waves.—As has been already remarked, the courses of the particles of water are not always strictly circular, as we have

assumed them to be in our figures, or even curves returning into themselves. This circular course is often converted into an elliptical form, sometimes the horizontal, sometimes the vertical diameter being the greater. If the horizontal diameter were null, the separate particles would merely oscillate up and down at right angles to the direction in which the waves are propagated. This kind of motion propagates the waves along a stretched cord. We shall on a future occasion have more to say regarding this kind of undulatory motion when we enter upon the theory of light.

FIG. 181.



The lines marked from 1 to 6 in Fig. 181, are designed to illustrate the transmission of such linear waves. These lines correspond accurately with the Figs. 176 to 180, being derived from the latter, on setting down the horizontal part of the motion as null; and they will not, therefore, require any further explanation.

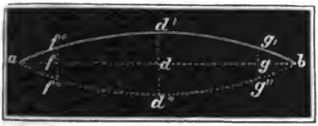
If a linear-wave advancing towards one fixed point reach that point, it will be reflected returning to the other end, and will pass many times backwards and forwards. But if new waves be continually formed, they will, in meeting the reflected waves, form *standing waves* from the combined action of the two systems of waves.

We will not here pause to consider any further the formation of *standing waves* by the combined action (interference) of the direct, and the reflected wave-system, since we purpose treating more fully, and on similar principles, of the formation of standing air-waves, depending on the interference of a direct and reflected wave system; at present we will limit ourselves to the consideration of the kind of motion manifested in a line or cord during such standing vibrations.

The most simple case is where the line vibrates throughout its

whole length as represented in Fig. 182. This motion may be brought about by removing the centre of a moderately tensely drawn line, somewhat out of its equilibrium (which is best done by moving it somewhat to the right or left) and then leaving it to itself.

FIG. 182.



All the particles are simultaneously on one and on the other side of the position of equilibrium; they simultaneously attain the maximum of their distance from the point of equilibrium on the right side, and simultaneously come to the extremities of their course on the other side. The particles, therefore, whose points of equilibrium are f, d and g, simultaneously reach f', d' and g'; and simultaneously passing their point of equilibrium, moving in the same direction, they simultaneously come to f'', d'' and g''.

While all the particles are always at the same time in similar conditions of equilibrium, the amplitude of their oscillations is alone different, being greater for the particle d than for f and g.

The oscillations of a tense string disturbed from its position of equilibrium, or those induced by a bow drawn across the middle of its length, are of the same kind. But the vibrations of the string are so rapid, that the separate oscillations can no longer be distinguished, but on the contrary only a tone is produced. We shall have once more further to consider the vibrations of the cord with reference to this tone.

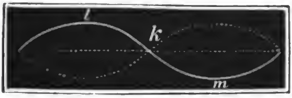
The vibrations of a somewhat loosely strung cord are slow enough to be counted; it is difficult, however, to produce a wholly regular oscillatory motion in the manner indicated, if we bring the middle of the line out of its equilibrium from below, since in that case not only the elasticity of the line will bring back the particles to their conditions of equilibrium, but gravity will also act; but if we move the middle of the line out of its equilibrium to the right or left, the motion is partially that of the pendulum, because if the line be not too tightly strung, the middle always hangs somewhat down; if, however, we draw it tighter, the vibrations become too rapid to be distinguished.

These regular vibrations in a string are best distinguished, if one of its extremities be fastened, while the other is held in the hand, and made to describe small circles with uniform velocity. When we find the right degree of rapidity for the motion of the hand,

which is easily done, the string will fall into such motion, that its centre will describe a large circle around its point of equilibrium. All the other points of the line then turn likewise in circles round their positions of equilibrium; the circles being smaller, the nearer the points lie to the extremities.

If we accelerate the motion of the hand, the regularity of the motion of the string will be disturbed; it is easy, however, so to accelerate the rapidity of the motion of the hand, that there shall be a point of rest in the middle of the string. Each half will vibrate exactly as did the whole line in the former case; the middle of each half describes larger circles than the other points, and here, therefore, a belly is formed. In Fig. 183 we have represented two ventral points, and one node, for thus we term the resting point *k*, separating the two vibrating portions.

FIG. 183.



When *l* reaches its highest point, *m* attains its lowest position, and conversely.

By increased rapidity of the hand, we can easily succeed in producing two nodes, and three bellies as represented at Fig. 184.

FIG. 184.

In the same manner the line may be divided into many parts, always separated by a node.

The nodes may also be observed in tense cords. Fig. 185 represents a tense cord from which $\frac{1}{3}$ of the length has been separated by means of a bridge, which so divided the cord into two parts, that the one is twice as long as the other. On touching the smaller parts with the bow, the other portion will fall into vibrations, and one node at *n*, and two bellies at *v* and *v′* will be formed. The position of these nodes is proved by little figures of paper remaining fixed at these points, which fall off at other parts of the cord.

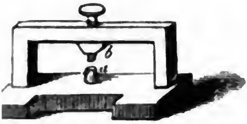
FIG. 185.

If we so arrange the bridge, that the string is divided into two parts, of which the one is only $\frac{1}{4}$th the length of the other, we shall have two nodes and three bellies on touching the string with the bow.

In metallic plates, bells, &c., regular vibrations may also be

roduced. In order to make plates vibrate, we may use the vice shown in Fig. 186, which must be firmly fastened. The plate is placed between the cylinder *a* and the screw *b*, both of which terminate in a piece of cork or leather. If the plate be sufficiently well screwed on, we may produce ibrations by strokes of the bow.

FIG. 186.



We may then cause plates of wood, glass, metal, &c., to vibrate, hether they be triangular, square, round, elliptical, &c. The brating plates produce like the vibrating cords, tones which are ometimes high, and sometimes low. It is observed further that e plates may be separated into vibrating parts, and *lines of repose* nodal lines for each one of these tones. In general the extenon of the vibrating parts diminishes, and consequently the nodal nes become more numerous, as the tone rises.

In order to prove the existence of these nodal lines, we may rew fine dry sand on the upper surface of the plate, when the nd will rise and fall during the tone, and at last accumulate pon the nodal lines. In this manner arise the sound-figures as ey were named by their discoverer *Chladni*.

A number of different figures may be produced by means of the me plate, according as we move the bow more or less violently, with more or less rapidity, or again according as we change e point of support of the plate, and touch various parts its edge.

At Figs. 187 and 188, a number of sound figures are repre-

FIG. 187.

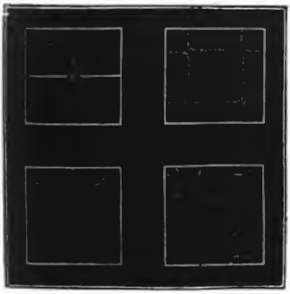
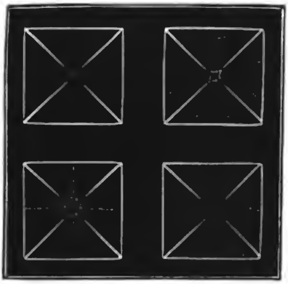


FIG. 188.



nted as produced with a square plate. For example, in order

to obtain the cross whose arms unite the middle points of the parallel sides of the square (see the first figure) we must fix the middle of the plate, and move the bow at one corner. By fixing the middle of the plate, and moving the bow in the middle of one side of the square, we form a cross, whose arms unite the opposite corners of the square Fig. 188.

Triangular and polygonal plates yield similar results.

Transmission of sound through the atmosphere.—The vibratory motion of any body surrounded by air gives rise in it to an undulatory motion, which on being transmitted to the ear produces the sensation of sound. Generally speaking, it is by means of the atmosphere that the sound-waves are transmitted to our organs of hearing, but still all other elastic bodies, solid as well as fluid, are capable of conducting sound more or less perfectly. Sound cannot, however, be transmitted in a *vacuum*. Let us lay a small cushion of wool or cotton in the middle of the plate of the air-pump, on the top of this a piece of clock-work provided with a little bell, and which can be made to strike. Over the whole is placed a bell glass, provided above with a leather cap, through which a rod passes, by whose turning the clock-work is set into action. At the instant the works begin to act, the clapper strikes at the intervals upon the bell; no sound, however, will be heard, if the bell have first been exhausted. On gradually admitting the air, we distinguish the tone becoming louder and louder as the bell becomes more filled with air. Sound cannot, therefore, be propagated through a vacuum.

The loudest noise on earth cannot, therefore, penetrate beyond the limits of our atmosphere, and in the same manner not the faintest sound can reach our earth from any of the other planets; thus, the most fearful explosions might take place in the moon, without our hearing anything of them.

Saussure asserts that the discharge of a pistol makes less noise on the summit of Mont Blanc, than the report of a small toy cannon fired off in the valleys below; and *Gay Lussac* found that when he had risen in his balloon to an elevation of 700 metres, and was consequently in a highly rarified atmosphere, his voice had lost very much of its intensity.

Sound may diffuse itself not only through the atmosphere, but through all kinds of gases and vapours. To prove this, we will hang a little bell to an untwisted hemp line in a large balloon (see Fig. 189).

FIG. 189.

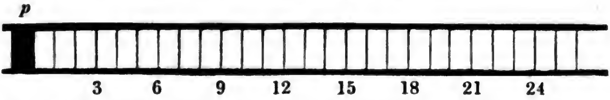
If the air be exhausted in the balloon, we shall no longer hear the sound of the bell; as soon, however, as a few drops of a volatile fluid, as for instance, ether, be introduced into the balloon, vapour will be immediately formed, and the tone will again become audible. Sound is readily transmitted in water; the diver can hear what is said on the shore, while persons on the shore can distinguish the noise made by the concussion of two stones at great depths low the surface.

Solid bodies can not only produce, but also transmit sound. If apply the ear to one extremity of a beam, 20 or 30 metres in gth, we can clearly hear a slight tap made at the other end of although the sound may be so indistinctly conveyed by the air at the person causing the noise may be scarcely conscious of it.

In order to comprehend the way and manner in which vibrations sound are transmitted through the atmosphere, we will suppose air at one end of an open tube to be put into a condition of oscillation by the vibratory motion of a piston applied at the other extremity.

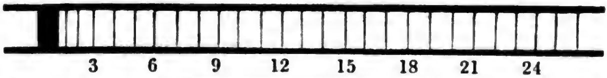
G. 191.

Fig. 190 represents such a tube; the lines drawn at equal distances designate strata of air of equal density; *p* is the piston which moves rapidly backwards and forwards along the distance *a g*, Fig. 191.

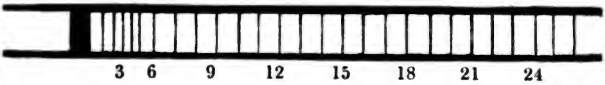


. 190.

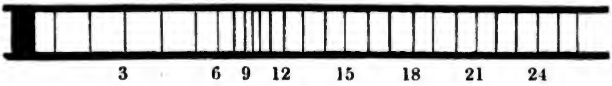
. 192.



. 193.



. 194.



Such an oscillating motion cannot, as we have already said, be iform. Let us suppose the time necessary for the piston to move ckwards and forwards, that is, from *a* to *g*, and again from *g* back to

a, to be divided into twelve equal parts; it will traverse in the first of these periods the distance *a b*, in the second the distance *b c*, in the third *c d*, &c.; the motion which was at first slow, increases therefore in rapidity, which at the end of the third period of time is at its maximum; at the sixth division of time it is at 0, when the piston reaches the right extremity of its course, and then begins its retrograde motion.

We obtain the points *b c d*, &c., by drawing a circle, whose diameter *a g* is equal to the amplitude of the oscillation, dividing the circumference of this circle into twelve equal parts, and letting fall perpendiculars from these points upon *a g*.

Now this motion of the piston is transmitted by degrees to all the separate layers of air of the tube, each of which will after a time make the same oscillations as the piston; the motion beginning later in proportion as each layer is further removed from the piston.

If the air were perfectly unelastic and rigid, the whole column of air in the tube would be pushed out by the motion of the piston, all the separate layers of air acquiring simultaneously the motion of the piston; but air is elastic, and motion is only gradually propagated by the layers nearest the piston being first compressed, and then by their elasticity acting upon the succeeding ones.

If we consider the condition of the air at the moment at which the piston, after the beginning of its motion, has traversed half its course towards the right, being consequently removed the distance *a d*, as represented in Fig. 192, from its original position, we shall see that motion has only been transmitted to the layer of air, marked 3; that is to say, the layer of air 3 is still in its original position; the air between it and the piston being compressed, this layer 3 is also urged forward, and thus begins its motion.

The layers of air 1 and 2 (not marked in the figure, because from their position there can be no doubt which are intended), have begun their motion subsequently to that of the piston, and are therefore not so far removed from their original position. The layer 1 began its motion later by $\frac{1}{12}$th of time necessary for the piston to pass backwards and forwards; the layer 2, $\frac{2}{12}$ths later; 1 has, therefore, been moved the distance *a c* from its original position, and 2 only the distance *a b*.

In this manner the mutual position of the layers of air between 3 and the piston may be ascertained as exhibited in Fig. 192.

Fig. 193 shows the piston at the moment in which it has reached the right end of its course, and consequently is removed the distance *a g* from its original position. Motion has in the mean time been transmitted to the layer of air 6, which then begins to move.

The piston has just come to rest, and is about to begin its retrograde motion; 3 has, however, just attained the greatest velocity in its motion from left to right.

The layers of air are removed from their original position as represented in Fig. 190 to the distances represented in the accompanying table.

The layer	1	is removed	to the	distance	*a f*
,,	2	,,	,,	,,	*a e*
,,	3	,,	,,	,,	*a d*
,,	4	,,	,,	,,	*a c*
,,	5	,,	,,	,,	*a b*
,,	6	,,	,,	,,	0

Fig. 193 represents the position above indicated of the various layers. The greatest condensation of the air occurs at 3.

While the piston now returns from its position at Fig. 193 to its original situation, motion is propagated to the layer 12; this layer of air begins its motion for the first time at the same moment in which the piston begins a second time to move towards the right. This position of the separate layers of air between 12 and the piston as represented at Fig. 194, takes place by the following consideration.

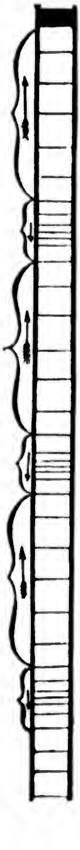
While the piston and the layer of air 12 assume their original position, and are momentarily at rest, all the intermediate layers of air are removed from their original positions; all the layers of air between the piston and 6 have a retrograde motion from right to left, while those between 6 and 12 go from left to right. The layers of air are removed from their original positions, as indicated in the table below.

The layer	1	is removed	the length	*a b*
,,	2	,,	,,	*a c*
,,	3	,,	,,	*a d*
,,	4	,,	,,	*a e*
,,	5	,,	,,	*a f*
,,	6	,,	,,	*a g*

The layer	7	is removed	the length	*a f*
„	8	„	„	*a e*
„	9	„	„	*a d*
„	10	„	„	*a c*
„	11	„	„	*a b*
„	12	„	„	0

We see here that at 9 there is the greatest condensation, and at 3 the greatest rarefaction; the layer 3 has just attained its greatest velocity towards the left, and the layer 9 towards the right.

FIG. 195.



If now the piston remain at rest, the layers 1, 2, 3, 4, &c., will successively return to their original positions, remaining at rest while motion is transmitted towards the right; at the moment, for instance, in which 3 recovers its original position, motion will be transmitted to 15; the maximum of condensation will be at 12, and the maximum of rarefaction at 6; at the moment in which 12 recovers its original position, the maximum of condensation has advanced to 15, and the maximum of rarefaction to 21, when the layer 24 begins its first motion.

From the piston to 12 there is one wave, from 12 to 24 a second; for the length of a wave is the distance between two particles in similar conditions of oscillation; the piston and the layers 12 and 24 begin their motion simultaneously to the right; they traverse their course in the same direction, returning in like time and manner.

Each wave consists of a rarefied and a condensed part; the former corresponding to the wave depression, the latter to the wave elevation of water-waves.

The distance from one point of the maximum of density to the next, that is from 9 to 21, and likewise the distance from one point of the maximum of rarefaction to another, consequently from 3 to 15 is also the length of a wave.

Fig. 195 represents the moment in which the piston having completed its oscillation for the third time, has created three perfect and successively advancing waves. The layers that move in the same direction are indicated in the figure by being joined together by

brackets. The middle of one of these divisions always corresponds to a maximum of condensation or rarefaction, the layers of air being at the highest point of their speed either to the right or left. The layers of air occurring at the points of contact of two brackets are momentarily at rest, being either at the right or left extremity of the course, which they traverse during their vibrations.

Since, as we shall presently see, the speed with which sound-waves are transmitted is independent of the time during which each individual particle makes a complete oscillation, and since the wave-length is the distance which a wave advances whilst a single layer of air is completing a perfect oscillation, it is clear that the wave-length increases in the same proportion as the time of oscillation for the separate layers of air. If the piston, and consequently the succeeding layers of air, require double, triple, and quadruple the time to make one oscillation, that is one backward and forward motion, the wave-length would become twice, thrice, or fourfold as great.

We have here, for the sake of simplicity, considered the propagation of air-waves in a tube; waves in free air are, however, transmitted in the same manner from oscillating bodies in all directions; as circular waves are formed around the spot in the water in which the stone has fallen, so also do spherical air-waves arise round the oscillating body.

We have now seen the manner in which sound (meaning thereby all action on the organs of hearing) arises and is propagated; the impressions produced upon our hearing are, however, very various in their nature. The sound heard from a sudden and single blow, as from an explosion or any other cause producing strong condensation of the air, and then advancing in the manner already considered without being succeeded by further waves, is termed a *report*; a sound, on the contrary, arising from regular oscillations, and propagated by regularly succeeding equal waves, is called a *tone*. If the undulatory motion transmitted by the sound to the ear become more and more irregular, the *tone* is converted into *noise*.

There are great differences between *tones*, the greatest being that manifested between *high* and *low* tones. The height of the tone is proportional to the shortness of the times of oscillation of the body producing it, and to the shortness of the air-wave propagating it.

The *intensity* of the tone does not depend upon the times of the oscillations or the wave-length, but upon the amplitude of the oscillations; the greater the latter is in the sounding body, the more considerable is the amount of condensation and the succeeding rarefaction of the air-waves transmitting the tone.

The *sound* or *quality* of the tone is far more difficult to define than its intensity; at an equal elevation of tone, the character of the tones produced from a violin are very different from those of a flute; natural philosophers are not agreed as to the cause of this difference, but it is probable that it depends upon the order in which the velocities and the changes of density succeed each other in the different layers of air intervening between the two ends of the waves; and that in many cases the condensed and rarefied parts of the same may be unsymmetrical.

Velocity of Sound.—All tones, whatever be their height or depth, their intensity or quality are propagated through the atmosphere with equal velocity, for if different persons listen to a concert from different distances, they hear exactly the same measure and harmony, which would be impossible if the higher tones advanced with greater or less rapidity than the lower tones.

While light is propagated with a velocity that cannot be computed by human measurement, sound requires a given time to advance to any distance, and hence we are enabled to explain several phenomena which we have often occasion to observe. If, for instance, we watch from some distance a stonemason at work, we do not hear the sound of the blow at the moment in which we see the hammer strike, but only after it has been raised, as if the sound were produced by the removal of the hammer from the stone, and not by its contact with it. On seeing a regiment march to the measure beaten on the drums preceding them, we observe an undulatory motion transmitted from the drummers through the whole rank, which is explained by the fact that all the men do not advance simultaneously, owing to the hindmost hearing the beats of the drum later than the foremost.

The rapidity of sound may be ascertained by the very simple means of noting the time that intervenes between the flash and the report of a cannon discharged at a known distance from the observer. This observation admits naturally of being most readily carried out at night. Several very exact experiments of this nature were made by a party of scientific men, at Paris, in 1822. The distance between the cannon and the observer was 9549,6

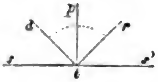
ses (1 toise = 6 Paris feet), and 54,6 seconds intervened :ween the flash and the report; whence it follows, that sound vels in an ordinary state of the atmosphere 174,9 toises = 1049,4, in round numbers, 1050 feet = 340,88 metres in a second.

Through other media the rapidity of the propagation of sound is : the same; being transmitted through iron $16\frac{2}{3}$, and through ter $4\frac{1}{2}$ times faster than through the air.

On the reflection of sound, and on the echo.—On passing from one dium to another, sound-waves always experience a partial reflecn; while on coming in contact with a solid impediment, they are nost entirely reflected.

Whether the reflection be partial or entire, the angle of reflection is always equal to the angle of incidence.

FIG. 196.



Let *s s′*, Fig. 196, be the separating surface of the two media, say air and water, and suppose a sound-wave move in the direction *d i* against the surface of the water, one portion of the motion will pass over to the water, nile another will be transmitted in the direction *i r*, which makes great an angle with the perpendicular *i p* as *d i*; that is to say, e angle of reflection *r i p* is equal to the angle of incidence *d i p*. ie same phenomenon would occur, according to the same law, if ′ were the separating surface of two gases, or merely of two yers of gas of different density, or if *s s′* were the bounding rface of a solid body, excepting that in the latter case the flected tone would be far more intense. An observer, therefore, anding at any point of the line *i r*, would hear the sound as if sued from *i*, or from a point in the prolongation of the line *r i*. n this general principle rests the explanation of an *echo*.

If the *echo* send the tone back to its starting point, the und-waves strike the reflecting surface at right angles. In is case, an echo may repeat a larger or smaller number of llables under conditions that may be easily ascertained. If e speak fast, 8 syllables may distinctly be uttered in 2 seconds, it in that period of time sound traverses twice 340 metres; if, ierefore, an echo be at a distance of 340 metres, all the syllables ill be given back in their proper order, the first coming to the eaker in 2″, that is, when he has given utterance to the last llable. At this distance, an echo may therefore repeat 7 or 8 llables; there are, however, echoes capable of giving back 14 or 5 syllables.

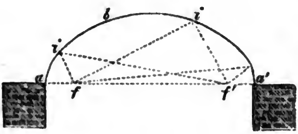
The reflecting surface need not be hard and flat, as we often observe at sea that clouds form an echo.

Sound-waves must also be reflected in a cloudless atmosphere when the sun develops heat with its full force on the earth's surface, since the radiation of heat cannot be equal in all parts, owing to dampness, shade, and other causes. This unequal temperature occasions a number of warm ascending and cold descending currents of air, of unequal density; as often, therefore, as a sound-wave passes from one current of air to another, it will experience a partial reflection; and if this be not strong enough to occasion an echo, it will at any rate materially weaken the direct tone. This is evidently the reason, as *Humboldt* observes, that sound is propagated further by night than by day, even in the midst of the woods of America, where the many silent animals in the day fill the atmosphere during the night with a thousand confused noises.

The explanation of *multiple* echoes, that is, such as give back the sound many times, rests upon the same principles; for as one reflected tone can be returned anew, it is evident that two reflecting surfaces may mutually reflect a tone, as two opposite mirrors reciprocally reflect light. Thus, an echo of this sort may arise between two distant parallel walls. There was formerly an echo of this kind at Verdun, occasioned by two contiguous towers, which repeated the same word 12 or 13 times.

There are likewise echoes which bear a tone to a definite spot.

FIG. 197.



Let us assume that the diagonal section of an arch is an ellipse, see Fig. 197, whose foci are f and f'. A tone issuing from f will be reflected from all parts of the arch to f', it being a property of an ellipse, that if we draw lines from f and f' to the same point of the curve, they will form equal angles with the normal of this point. If, therefore, one person stand at f, and another at f', they will be able to understand each other, although they may speak in a low voice, and the distance of the two points f and f' amount to from 50 to 100 feet while not a word can be heard at the intervening points.

The actions of the speaking-trumpet and the hearing-trumpet may also be explained on the principle of the reflection of sound.

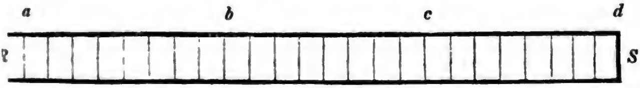
CHAPTER II.

LAWS OF THE VIBRATIONS OF MUSICAL TONES.

Formation of regular Air-waves in covered pipes.—If a sound-
ve enter the open end of a tube closed at the opposite extremity, will be reflected on the surface of the tube, but the reflected ves meeting the newly entered waves will form standing air-ves by the combined action of both wave systems, provided the igth of the pipe bear a proper proportion to the length of the ınd-wave.

If we assume the length of the tube *R S*, Fig. 198, to be ¼th of

FIG. 198.



: length of the sound-wave entering it, then the distance from : opening to the bottom, and back from the bottom to the ening is exactly ½ a wave-length, the waves of incidence and lection which meet at the opening of the tube are, therefore, noved from each other half a wave-length in their course; the ıximum of the density of the wave of incidence coinciding, :refore, with the maximum of the rarefaction of the wave of lection, and conversely, at the opening of the tube there is, :refore, neither condensation or rarefaction.

Let us now consider the condition of motion of the layer of air ing in a state of equilibrium the opening of the tube.

We have already seen in Fig. 194, that if there be a maximum density in a definite spot, as at 9, the particle 6, whose position rest lies one fourth of the wave-length from the point of rest of : particle 9, will be moved to the furthest point from its position equilibrium in the direction of the advancing wave, whilst the

particle 12, whose position of equilibrium lies one fourth of a wave length further on than the position of equilibrium of 9, will assume at this moment a state of equilibrium.

At the moment, therefore, in which the maximum of density of the incident wave meets the bottom of the tube, the layer of air at the opening has been moved to its maximum advancement toward the right, by means of this incident-wave, while at the same moment it is not driven to the opposite side by the reflected wave; thus it appears that at the instant in which the wave of incidence arrives at the bottom of the tube with the maximum of rarefaction, the layer of air at the entrance has experienced its furthest removal to the left from its position of equilibrium, by the influence of the reflected wave; the layer of air at the entrance of the tube vibrates, therefore, alternately from right to left, that is, towards and from the bottom, without, however, any condensation or rarefaction occurring.

All the remaining layers of air in the tube have now simultaneously a similar motion, the extent of the vibrations being small in proportion as they lie near the bottom. This is illustrated in Figs. 199, 200 and 201. Fig. 199 represents the separate layers

FIG. 199.

FIG. 200.

FIG. 201.

of air in the tube in their positions of equilibrium; from this position of equilibrium they move simultaneously towards the right, reaching the position of Fig. 200 after one fourth of an undulation. In this position of the layers, the air is naturally strongly condensed at the bottom of the tube. All the particles then move simultaneously from the bottom, simultaneously passing the position of equilibrium, and simultaneously reaching the position indicated at Fig. 201. At this moment, a rarefaction takes place at the bottom of the tube.

Our drawing has been, for the sake of clearer illustration, exces-

vely exaggerated, at least as far as relates to the amplitude of scillation as occurring in a pipe of the length represented, for the yer of air in a state of equilibrium at the entrance of the pipe ould not enter so far into it, or pass so far out of it, but merely scillate a little to the right and left during the vibrations. If, owever, the amplitude of oscillation had not been taken on so rge a scale, it would have been difficult to indicate clearly the ifference between the condensation and rarefaction.

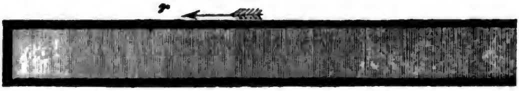
Here, therefore, a regular wave has also been formed by the nterference of the direct and reflected waves, for all the separate yers of air in the tube begin their motion simultaneously, simul- neously reaching the limits of their course, and then beginning eir motion in opposite directions.

Figs. 202, 203, 204, are intended to illustrate the rarefactions nd condensations alternately produced in such regular air-waves.

FIG. 202.

FIG. 203.

FIG. 204.



n Fig. 202 the whole tube is uniformly shaded, and corresponds o the case where the air is of uniform density throughout the hole tube, as it is in the moments at which all the individual yers of air pass their position of equilibrium with their maximum peed. If the particles have come to the extreme points of their ourse in their oscillation towards the closed end of the tube, a ondensation takes place as seen in Fig. 203.

Now the separate layers of air begin to move away from the losed end, and after half an undulation, we have a rarefaction as n Fig. 204.

At the open end of the tube there is at no moment of time any narked condensation or rarefaction, the layers of air moving

FIG. 205.

backwards and forwards between the furthest limits. The arrows in Figs. 203 and 204 indicate the direction in which the particles begin to move, when the condensation or rarefaction has just reached its maximum at the bottom.

If now a hole be made in the tube at *r* for instance, it will hinder the formation of the regular wave, because the air will escape thence at the moment of condensation, and flow in again at the moment of rarefaction. But the disturbing influence of such an opening would be less considerable at the places nearest the open extremity, since rarefaction as well as condensation would be less at such points.

Cutting away the tube at these parts would produce the same disturbing effect as an aperture.

The formation of a regular air-wave in the tube is, therefore, dependent upon certain relations existing between the length of the tube and the wave-length of the incident tone; in the case we have considered, the length of the tube was one fourth of the wave-length of the incident tone; standing air-waves may, however, be found in the tube under other relations than those we have considered between the tubes and the wave-length.

It is essential to the formation of regular waves in the tube, that the amplitudes of oscillation should become so small as almost to disappear close to the bottom, but that an alternate state of rarefaction and condensation should take place, while no such apparent changes are going on at the entrance of the tube, since *there* the condensed part of the reflected wave must always coincide with the rarefied portion of the incident wave, and inversely.

This condition is certainly complied with in making the opening of the tube $\frac{1}{4}$ of a wave-length from the bottom, the same, however, is effected by letting the distance between the entrance and bottom of the tube amount to $\frac{3}{4}$th, $\frac{5}{4}$th, $\frac{7}{4}$th, &c., of the wave-length.

In Fig. 205 the line $a\ b$ represents the length of the tube amounting to $\frac{3}{4}$ths of a wave-length; if then $b\,c = c\,d = d\,a = \frac{1}{3}\,b\,a = \frac{1}{4}$th of the wave-length, the rarefied portion of the wave will be at *c*, as the wave system advances from *a* to *b*, while

he condensed part will be at *a*, because *c* and *a* are removed $\frac{1}{2}$ a vave-length from each other. If the wave system were to extend beyond *b*, a condensation would again occur at the same moment it *c*′, and a rarefaction at *a*′, consequently there would be like conditions at *a* and *c*′, and opposite conditions at *c* and *a*′; but now he wave is reflected at *b*, *c*′ therefore coincides with *c*, and *a*′ with *a*; condensation and rarefaction will consequently cease at *c* as well as at *a*; there being nothing at these points but a simple motion backwards and forwards of the layers of air without any marked change of density.

Let us now see what goes on at *d*.

If the maximum of density be advanced from *a* to *d*, it would also have gone on from *c*′ to *d*′ if there were no reflection at *b*; at *d* and *d*′ there are consequently always equal conditions of oscillation; but by the reflection at *b*, *d*′ is thrown upon *d*; hence the maximum of the density of the incident and reflected waves, and $\frac{1}{2}$ an undulation later, the maximum of the rarefaction of both coincide; and consequently there will be here alternately an increased condensation and rarefaction.

If now we investigate the condition of oscillation of a layer of air at *d*, we shall find that it has no motion, for if the waves advanced beyond *b*, there would be equal conditions of oscillation at *d* and *d*′ which would always move towards the same side with uniform velocity, but if the wave system be reflected, the reflected wave of the layer of air *d* will impart an opposite motion to that which it would have imparted without any reflection of the layer of air *d*′; *d* is therefore always affected by both wave-systems with equal, but oppositely directed velocities; and consequently this layer of air must remain at rest.

The Figs. from 206 to 208 show the air-waves formed in a tube $\frac{3}{4}$ths of the length of the incident sound-wave.

FIG. 206.

FIG. 207.

FIG. 208.

In Fig. 206 we see a maximum of condensation at *d*, and a maximum of rarefaction at the bottom of the tube at *b*; all the layers of air lying to the left of *d* simultaneously begin their motion in the direction indicated by the arrow; whilst the layers lying to the right of *d* begin to move towards the right.

After ¼ of an undulation, the separate layers have reached such a position that the air is of uniform density throughout the whole tube, as intended to be represented in Fig. 207; after another ¼ of an undulation moving in the direction indicated, the condition represented in Fig. 208 will occur; now there is the greatest condensation at *b*, and the greatest rarefaction at *d*.

From this moment the separate layers of air again begin to move towards *d*, and then the condition represented in Fig. 206 recurs after ½ of an undulation.

The layers of air lying to the right and left of *d*, either move simultaneously away from, or simultaneously towards *d*, which has no motion; the layer of air *d* forms, therefore, a *node of oscillation.*

The points *c* and *a*, where there is neither rarefaction or condensation, but where the layers of air oscillate with the greatest amplitude, are termed *bellies.*

In order to put the air within a closed tube into such standing vibrations, it is only necessary to bring an oscillating body before the open extremity of the tube, which may give such a tone, that the length of the tube is equal to ¼, ¾, 5/4, &c., of the wave length of the tone.

We may use for this purpose an ordinary tuning fork, holding it over a glass tube of about two inches in length, closed below; or we may take a glass or metal-plate in the same manner as when used to produce *Chladni's* figures by the help of the bow of a violin, holding a tube, closed below, under it. If the tube be of the right length, the enclosed air being thrown into a state of standing vibrations, will become resonant, considerably increasing thereby the intensity of the tone, as may be clearly perceived by passing the sounding body backwards and forwards before the opening of the tube; the tone becoming alternately stronger and

weaker as the body is brought to the opening or beyond it. If the tube should be too long for the sounding body that is used, it may easily be brought in accordance with it by pouring water into it; that is to say, it may be thus shortened until it have the length proper for the sounding body.

In order to throw the enclosed air into regular vibrations, or to make it resonant with the sounding body, it is not indispensably necessary to bring a sounding body before the opening of a tube. Thus in organ pipes there is a current of air flowing past the open end of the tube breaking against the edges, and creating by its impulses waves that are reflected on the bottom, and interfere with the newly incident waves. Although these impulses are at first not quite regular, they are soon regulated by the accession of reflected waves, provided the tube sound well, so that regularly standing waves are formed by means of which the air in the tube becomes resonant.

The notes yielded in this manner by a tube are of the same kind as those which must be given forth by another sounding body brought to the opening of the tube for the purpose of inducing spontaneous sound in the enclosed air.

The simplest way of making air sound in a small tube is by holding it in a vertical position before the mouth, turning the closed end downwards, whilst the open extremity is held to the lower lip, and we blow obliquely towards the edge of the tube.

Notes are naturally higher in proportion to the shortness of the pipes. Organ pipes have generally the arrangement represented in the following figures. We divide them into the *pedal* yielding

FIG. 209.

FIG. 210.

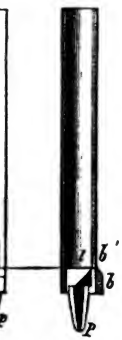


FIG. 211.

FIG. 212.

FIG. 213.

the wind, the *mouth* and the *tube* containing the column of air, the vibrations of which produce the note. The pedestal is hollow (Figs. 209 to 213) and through this cavity the wind passes by means of a fine slit into the tube. The mouth-piece $b\ b'$ is more or less open, that is to say, its upper part is more or less removed from the lower, and not unfrequently the former is moveable, so as to open or close the mouth-piece at will.

The organ pipes are filled with wind by means of bellows. If air be blown into the pedestal of the tube, there will be a thin layer formed at its passage from the air-hole, breaking against the upper lip, and thus imparting those impulses to the air in the tube which occasion the notes.

The same tube closed at one extremity may yield many notes. The deepest having a wave-length four times as great as the length of the tube; the higher notes of the pipe correspond to a wave-length three times, five times, &c., as short as the wave-lengths occasioned by standing vibrations having three times, five times, &c., as short a duration of oscillation as the deepest note of the pipe.

The pipe yields the deepest note with a faint wind, and the highest notes with a strong wind.

Open Pipes.—A stronger condensation of air may occur at the end than in the middle of the pipe, as the air cannot escape laterally from the former. If now the condensed portion of a wave arrive at the open extremity of the tube, the layers of air may easily escape in all directions on their passage from the tube, and a rarefaction thence arise; which being reflected as it were from the open end of the tube, traverses it in an opposite direction, and so standing waves are here formed.

The returning wave is naturally not so intense as the original one.

As a condensation always coincides with a rarefaction at the open extremity of the tube, a belly must necessarily arise here, while nodes of oscillation can only be formed in the interior of the tube.

If a wave-length l belong to the note of the body by which the air in the tube is to be brought to sound, the length of the shortest open tube corresponding to this note will be $\frac{l}{2}$; that is to say, the tube is half as long as the wave-length of its note. If, therefore, the deepest notes of one open and one covered pipe are to be equal, the open pipe must be twice as long as the other.

A node of oscillation occurs in the middle of the length of an open tube in forming the deepest note, and a belly at each extremity, as represented in Figs. 214 and 215.

FIG. 214.

FIG. 215.

Fig. 214 represents the moment when the greatest condensation takes place in the middle of the tube; while the layer of air remains at rest in the tube, the air begins to move away on both sides from the middle, as indicated by the arrow; rarefaction is at its maximum half an undulation afterwards in the middle of the tube, and now the layers of air begin to move towards the middle from both sides. In the next highest note, a belly occurs in the middle of the tube, and nodes at the points *a* and *b*, which are ¼ of the length of the tube from the extremities. If condensation be at its maximum at *a*, as represented in Fig. 216, then the rarefaction will be at its maximum at *b*, and conversely as seen in Fig. 217.

FIG. 216.

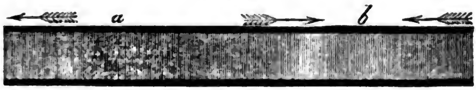
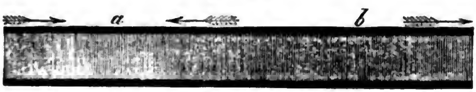


FIG. 217.



In the above case, the wave-length of the note is equal to the length of the tube, while the duration of oscillation of this note is half as great as that of the key-note of the tube.

The third tone that the tube can give has a wave-length 1½ times that of the length of the tube; in this tone there are three nodes of oscillation, one of which lies in the middle, and each of the remaining two at $\frac{1}{6}$ of the length of the tube, or ¼ of the wave-length of the engendering sound-wave.

If we designate the length of an open tube by l, the wave-lengths of the tones, it is capable of yielding:

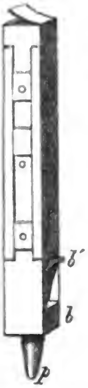
$$2\,l,\ \tfrac{2}{2}\,l,\ \tfrac{2}{3}\,l \text{ \&c.,}$$

whilst

$$4\,l,\ \tfrac{4}{3}\,l,\ \tfrac{4}{5}\,l \text{ \&c.}$$

are the wave-lengths of the tones that can be produced from a covered pipe of the length l.

FIG. 218.



If, now, at different parts of an organ-pipe we make holes that can be closed or opened at will, by a slide as represented in Fig. 218, we can prove that the tone will not be changed if the opening be made at a belly, although it would be altered were the aperture at any other part.

Musical notes.—As we have now learnt to know the means by which pure notes may be produced, as for instance through organ-pipes, and since we have seen how the height and depth of these notes depend upon the length of the pipes, and consequently that we may accord such pipes at will, by lengthening or shortening the tubes, we will proceed to consider the series of notes made use of in music.

Let us begin with the fundamental note yielded by a covered pipe, 4 feet in length; this tone is designated in music as the note C.

If we examine the notes, which combined with C will make an agreeable impression upon the ear, we shall find them to be those whose rapidity of oscillation stands in a certain relation to that of C; their wave-lengths are $\frac{1}{2}$, $\frac{2}{3}$, $\frac{3}{4}$, $\frac{4}{5}$, $\frac{5}{6}$ of the wave-length of C; and they are consequently those that would be produced by pipes whose lengths are $\frac{1}{2}$, $\frac{2}{3}$, $\frac{3}{4}$, $\frac{5}{6}$, of the length of the pipe C.

As the time of oscillation stands in an inverse proportion to the wave-length, the first of the above-named notes will make two vibrations while C makes only 1; this note is the octave of C, and is designated as c.

The note whose wave-length is $\frac{2}{3}$ of that of the note C, makes 3 oscillations while C makes 2; this is the fifth of C, and is designated as G.

The note, whose wave-length is $\frac{3}{4}$ of that of C, makes 4 vibrations while C makes 3; it is called the fourth of C, and is marked F.

The note, whose wave-length is $\frac{4}{5}$ that of the note *C*, makes 5 vibrations while *C* makes 4; it is the major third of *C*, and is marked *E*.

The last note to be mentioned, and whose wave-length is $\frac{5}{6}$ times as great as that of *C*, makes 6 vibrations while *C* only makes 5; it is the minor third of *C*, and is marked *E* flat.

As *C* has its octave, fifth, fourth, major and minor third, so there are likewise an octave, a fifth, a fourth, and a major and minor third for *c*.

The fundamental or key-note *C*, with its major third *E* and its fifth *G*, form the common chord of *C* major.

According to the above relations, the notes below make vibrations simultaneously, as follows:

C	*E*	*F*	*G*	*c*
24	30	32	36	48

In order to perfect the whole series of notes, *E*, *F* and *G* must have their accord, consequently their third and fifth, as well as *C*.

The fifth of *G* is a note vibrating 3 times, while *G* only performs 2 vibrations; there are, therefore, to 36 vibrations of *G*, 54 vibrations of its fifth, which we will designate as *d*; the next octave below *d* is marked *D*, and makes 27 vibrations to 36 of *G*, and 24 of *C*.

The major third of *G*, designated as *H*, must make five vibrations, while *G* only completes 4; there are, therefore, 45 oscillations of *H* to 36 of *G*.

As 24 is to 36 (that is, *C* to *G*), as 32 is to 48 (or *F* to *c*), c is the fifth of *F*.

The major third of *F* must make 5 vibrations, while the latter makes only 4; to 32 vibrations of *F* there will consequently be 40 of its major third, which we designate as *A*.

Thus we have a series of notes bearing the name of the *C* gamut. The simultaneous vibrations are as follows:

	C	*D*	*E*	*F*	*G*	*A*	*H*	*c*	*d*	*e* &c.
Vibrations:	24	27	30	32	36	40	45	48	54	60

The differences between each two succeeding notes of this series are not equal. In the following series, the somewhat deeper break between two numbers indicates how much the rapidity of oscillation of each note exceeds that of the succeeding one.

$$C \quad \tfrac{1}{8} \quad D \quad \tfrac{1}{9} \quad E \quad \tfrac{1}{15} \quad F \quad \tfrac{1}{8} \quad G \quad \tfrac{1}{9} \quad A \quad \tfrac{1}{8} \quad H \quad \tfrac{1}{15} \quad c;$$

D accordingly makes $1\frac{1}{8}$ times as many vibrations in the same period of time as *C*, *E* $1\frac{1}{9}$ times as many as *D*, *F* $1\frac{1}{15}$ times as many as *E*, &c.

The interval between *C* and *D*, between *D* and *E*, *F* and *G*, *G* and *A*, and *A* and *H*, is called a perfect tone; we distinguish them, however, as full perfect tones if the interval be $\frac{1}{8}$, and small perfect tones when it is only $\frac{1}{9}$.

The intervals between *E* and *F*, and *H* and *c*, are nearly half as large as the rest; they are therefore called semi-tones.

If we proceed from any of the other notes, advancing in the same order of intervals, we shall in the same manner obtain the various gamuts; in order, however, to proceed according to this arrangement of intervals for each note, we must insert half-notes between *C* and *D*, *F* and *G*, and *G* and *H*, marking them thus: *c* sharp, *e* flat, *f* sharp, *g* sharp, and *b*.

Through the gamuts we pass from the key-note to the major third; and then, passing over the minor third, to the fifth; in the soft-toned gamuts, on the contrary, the chord is formed by the key-note, the minor third and the fifths.

A fuller consideration of the kinds of tone and the gamut belongs to the theory of music, and would lead us beyond our limits.

If the fundamental, or key-note, make 1 vibration in a given time, the major third must make $\frac{5}{4}$ in the same time; the major third of this note will make $\frac{5}{4} \cdot \frac{5}{4}$ or $\frac{25}{16}$, and the third of this note $\frac{5}{4} \cdot \frac{5}{4} \cdot \frac{5}{4}$ or $\frac{125}{64}$ vibrations. The latter note does not exactly accord with the octave of the fundamental note, which corresponds to $\frac{128}{64}$; if, therefore, we proceed through full thirds, we do not reach a pure octave, and if we retain the purity of octaves we must abstract from the perfect purity of thirds. The same is the case with respect to pure fifths. We are, therefore, obliged to set the notes somewhat higher or lower than required for pure thirds or fifths, in order to retain the purity of the octave; the note must be suffered, in the ordinary language of musicians, to float somewhat over or under. This mode of balancing is called the *temperature*. It would carry us too far, however, to treat of the separate kinds of temperature.

If the ear were more sensitive than it is, it would be so unpleasantly affected by the impurity of the thirds and fifths, as almost to preclude any enjoyment from music.

As we have now become better acquainted with the various designations applied to notes, we may use them in speaking of the different tones yielded by the same pipe. In an open tube or

ipe, for instance, the second note is the octave of the key-note, 'hile in a covered pipe it is the fifth of the next higher octave.

The deepest tone applied in music is that yielded by a covered ipe 16 feet in length. But now we know that when a covered ipe gives forth its deepest notes, its wave-length must be exactly of the wave-length of the note; accordingly, the wave-length or this note must, in an ordinary state of the atmosphere, be 4 feet.

Sound travels about 1089 English feet in a second; if we divide iis number by 64, we find how many wave-lengths this deepest ote advances in a second; or what is the same thing, how many scillations are necessary in a second to produce this deepest iusical note, we find the number to be 16,4.

In like manner, we find how many oscillations the air makes in a econd in a covered pipe while giving its deepest note, by dividing our times the length of the pipe (expressed in Paris feet), y 1050.

Music altogether comprises 9 octaves. The deepest note already poken of, yielded by a covered pipe 16 feet in length, is desig-ated as $\underline{\underline{C}}$.

As this note makes 16,5 vibrations in a second, the following ible gives the number of vibrations for each of the successive ctaves of this tone:

$\underline{\underline{C}}$	16,5
$\underline{C}$	33
C	66
c	132
$\overline{c}$	264
$\overline{\overline{c}}$	528

With our notes the tones are thus expressed

Tones of stretched strings.—The most important laws of the vibrations of stretched strings are as follows:

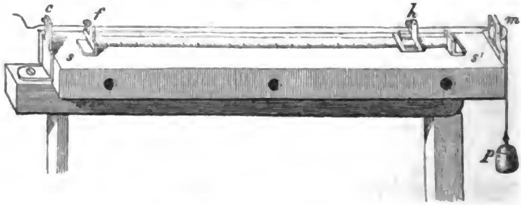
1. *The number of vibrations of a string is inversely as its length*; that is, if a string of any instrument, as a violin or a guitar, be stretched, and make a certain number of vibrations in a given time, it would make in the same time 2, 3, or 4 times as many vibrations, if with the same tension we let only $\frac{1}{2}$, $\frac{1}{3}$, or $\frac{1}{4}$ of the whole length vibrate; it would vibrate $\frac{3}{2}$, $\frac{4}{3}$, or $\frac{5}{4}$ times as fast if we only suffered $\frac{2}{3}$, $\frac{3}{4}$, or $\frac{4}{5}$, of the whole line to vibrate.

3. *The number of the vibrations of a string is proportional to the square root of the stretching weight*; that is, if the weight stretching the string were made 4, 9, or 16 times as great whilst the length remained unaltered, the velocity of the vibrations would be 2, 3, or 4 times as great.

3. *The number of vibrations of different strings of the same substance is inversely as their thickness.* If, for instance, we take two steel wires of equal length, whose diameters are as 1 to 2, the thinner will with equal tension make twice as many vibrations as the thicker. This law does not always hold good for catgut strings, as they are not absolutely made of the same substance.

An instrument called a *monochord* is used to illustrate the most important laws of stretched strings and their notes, which gives out pure notes, and admits of the length of the strings being measured with great exactness. Fig. 219 represents a monochord. We may

FIG. 219.



stretch a catgut or a metal string to prove that both follow the same laws. The string attached at *c*, goes over a kind of bridge at *f* and *h*, then over a pulley *m*, being finally loaded with the weight *p*. The moveable bridge *h* may be pushed along without touching the string, and secured by a press-screw to any part we choose. We shall presently see how the hollow box *s s'* serves to strengthen the note. If now we suppose the string to be sufficiently stretched when vibrating freely to give a full and sure note, which we will

sume to be the starting point of *c*, we may by moving the bridge ake the string yield successively the notes *d*, *e*, *f*, *g*, *a*, *h*, and *c*. we designate the length of the string, giving the fundamental ›te *c*, as 1, we shall obtain the following lengths of string for the her notes:

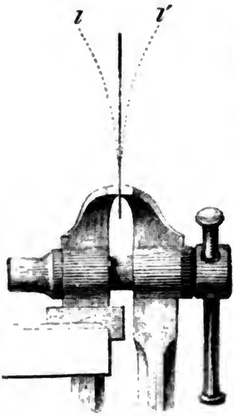
c	*d*	*e*	*f*	*g*	*a*	*h*	*c*
1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$

We must, therefore, make the string half the length in order to ake it yield the octave, other conditions remaining the same. ut as the octave makes twice as many vibrations as the funda- ental note, a string half the length will make double the number vibrations.

To obtain the fifth, we must shorten the string to $\frac{2}{3}$ of its length; ıt the fifth makes $\frac{3}{2}$ times as many vibrations as the fundamental ›te in an equal time.

The number of vibrations of strings is, therefore, inversely as eir length.

FIG. 220.



To obtain an octave with an equal length of string, we must attach 4 times as heavy a weight, and $\frac{9}{4}$ as heavy a one for the fifth.

Laws of the vibrations of blade and rods.—If a blade or rod be fastened at one end (see Fig. 220), and be touched by the bow of a violin, or simply brought out of equilibrium by the hand, it will make a series of vibrations between l and l', which if sufficiently rapid, will produce a note. If different lengths be given to the same blade, the number of the vibrations made in a given time will be inversely as the square roots of the vibrating lengths.

Of reed-pipes.—A tongue is generally a vibrating plate set in motion by a current of air.

FIG. 221.

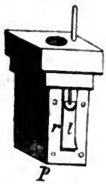
Let p (Fig. 221) be a plate of metal 2 to 3 millemetres in thickness, having a rectangular opening, *a b c d*, 3 centimetres in length, and from 7 to 8 millemetres in breadth, over which a very thin elastic brass plate is fastened, as represented in the diagram. This plate can vibrate on touching the edges

a b, *b c*, and *c d*. In this manner we have a very simple tongue-work, which can be set in motion by putting the plate *p* lengthwise to the lips, and blowing so as to direct the air against the free end of the plate *l*. The latter is made to vibrate by the current of air; the aperture is alternately opened and closed while the current first pours in, and then is checked in its course; in this manner sound-waves arise, whose length depends upon the number of vibrations which the dimensions and elasticity of the plate *l* admit of its making in a given time. With the exception of greater intensity, the note is the same as if the plate were made to vibrate by mechanical means. If we fasten several such bars to one plate, choosing such as will yield the succeeding notes of a gamut, we may make an instrument on which we may play various tunes.

The tongue-work of an organ depends upon similar principles, although in this case the tongue is differently attached. Here we distinguish two contiguous tubes, *t* and *t′* (Fig. 222) a stop *b* dividing them, and the actual tongue-piece passing through the stop. The tongue-work itself is represented on a larger scale in Fig. 223, and consists essentially of three parts, the channel *r*, the tongue *l*, and the tuning-wire *z*.

FIG. 222.

FIG. 223.



The channel is a prismatic, or half cylindrical tube, closed below, and open at the top, having an aperture at the side by which both tubes are joined together.

The tongue is the vibrating plate; in its natural position, the lateral opening of the channel is either entirely or almost closed by it; that is to say, it touches upon the edges of the opening with its three free edges during its oscillations; the fourth side being secured to the tube either by a screw or by soldering.

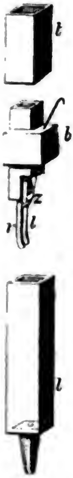
The tuning-wire is a strong metal wire, doubly curved below, and pressed against the tongue along its whole breadth. It may be pushed up and down in the stop with some friction, and thus the vibrating portion of the tongue may be lengthened or shortened, for the part over the tuning wire cannot vibrate.

The wind of the bellows enters through the pedal of the tube *t′*, and pressing against the tongue to procure an outlet, forces itself through the channel, and escapes from the tube *t*. The tongue

hus brought out of its equilibrium returns immediately by means f its elasticity, making vibrations in this manner, which last as ong as the current of air continues. Fig. 222 represents a reed-ipe in which the part of the tube opposite to the tongue is of lass, the better to show its working.

In organs the reed-pipes are often constructed somewhat differently, by the edges of the tongue striking upon the edges of the channel, as exhibited in Fig 224.

FIG. 224.



If a reed-pipe vibrate of itself in free air—if, consequently, no pipe, or only a relatively short one, be placed over it, its rapidity of vibration, and therefore its note, depend upon its elasticity and dimensions; if, however, a long tube be put on, it will essentially modify the note; the motion of the tongue depends, therefore, more upon the motion of the air-waves passing backwards and forwards in the long pipe than upon its own elasticity; it therefore vibrates less of itself than from external agents.

Transmission of vibrations of sound between solid, fluid, and aëriform bodies.—If several solid bodies be united together in a whole, the vibrations issuing from one part of this system distribute themselves with the greatest ease, as advancing waves over the whole mass; having reached the confines, the waves pass only partially into the contiguous medium, the aëriform or fluid body; they re partially reflected, however, and regular vibrations are formed 1 the separate parts of the solid system by the interference of the eflected with the fresh incident waves. Such a system forms a hole, which, if a point be made to vibrate, will be like a single olid body divided into separate vibrating parts, divided by nodes of scillation. Each separate part loses, to a certain degree, its individuality, while its connection with the contiguous parts hinders from vibrating as it would do if it were isolated.

While sound-waves are easily distributed over a system of solid odies, they pass less easily from a solid to a liquid, and with still ss facility to a gasiform body; thus it happens that many strongly ibrating solid bodies only yield a very weak tone, owing to their ıability properly to impart their vibrations to the air. This is the ıse with the tuning-fork, for instance, which gives forth only a ıint sound on being struck with force and held free in the air.

In order to heighten the tone of such a body, the transmission

of its vibrations through the atmosphere must be increased by *resonance*, that is, by endeavouring to transfer the regular vibrations of the sounding body to another. One means with which we are already acquainted is to bring the low-toned but strongly vibrating body before a tube of proper length, and to cause the enclosed air to sound.

A second method of strengthening the tone, is by bringing the sounding body in contact with another of proportionately large surface, and capable of being readily made to vibrate. There are then regular sound-waves formed upon it, as we have already mentioned, which are more readily transmitted to the air, owing to the large area of the sounding (*resonant*) body. If, for instance, we put the strongly struck tuning-fork, which yielded in the open air but a faint sound, upon a box of thin elastic wood, the note will be given with much more intensity. On this principle depends the sounding-board used in different musical instruments. In flutes, organ-pipes, &c., no such application is necessary, as the regular vibrations of a mass of air yield the note, and easily distribute themselves through the surrounding atmosphere.

As vibrations of solid bodies create sound-waves in the air, so likewise sound-waves may, when diffusing themselves through the atmosphere, cause a solid body to vibrate by coming in contact with it. Thus, for instance, we see the string of an instrument vibrate if it come in contact with the sound-waves of the note it yields, or with those of one of its harmonic notes; and in this manner the panes of glass in a window shake with violence from the influence of certain notes of the voice, or from the report of a cannon. This phenomenon, which is strikingly manifested in susceptible bodies, also occurs in larger masses and in less elastic bodies; all the pillars and walls of a large church shake more or less strongly during the ringing of the bells.

CHAPTER III.

OF THE VOICE AND HEARING.

The organs of speech.—It is well known that the wind-pipe is tube ending at one extremity in the throat, and in the other in e lungs. Its especial use is to give a free passage to air both in *spiration* and *expiration*; it is almost cylindrical, being composed cartilaginous rings, which are united together by flexible embranous rings. At its lower extremity, it separates into two bes, the *bronchi,* one of which goes to the right, the other to the ft. Each of these branches is further ramified in all directions the tissue of the lung. At its upper end the wind-pipe termi- ites in the *larynx,* which is essentially the organ of speech.

The *larynx,* consists of four cartilages. which ossify in extreme old e; they are the *cricoid,* the *thyroid,* and the two *arytenoid* carti- ges. These cartilages are connected with one another, and tewise with the upper rings of the wind-pipe, and may be moved the most varied ways by means of different muscles. The inner ill of the *larynx* forms a prolongation of the wind-pipe, contracting itil it becomes nothing more than a mere chink, directed back- ird, known as the glottis.

The edges of the glottis are principally formed by the *chordæ cales,* which merge anteriorly in the thyroid cartilage, while at opposite extremity one *chorda vocalis* is incorporated in the ier, and the second to the other arytenoid cartilage, so that cording as the cartilages are brought nearer to, or further from h other by the corresponding muscles, the *chordæ vocales* become re or less stretched, while the glottis diminishes or enlarges. e *chordæ vocales* themselves consist of a very elastic tissue.

Above the edges of the glottis there are two sac-like cavities, one the right, the other to the left side, stretching from eight to ie lines sidewards, and having a depth of five or six lines; these the *ventriculi morgagni.* The upper edges of these ventricals

form as it were a second glottis, lying five or six lines above the other. The upper glottis may be covered by the *epiglottis,* which is an almost triangular membrane, or rather a cartilage; it is attached to the glottis anteriorly, and when covering it, hinders all food and drink from getting into the wind-pipe, since they must pass over it to enter the œsophagus.

The formation of the larynx will be more clearly illustrated by the accompanying figures. Fig. 225 presents an anterior view of it; Fig. 226 gives a lateral view; Fig. 228 gives a posterior, and Fig. 227 a superior view, leaving out the muscles that move the

FIG. 225.

FIG. 226.

FIG. 227.

FIG. 228.

ırtilages, and thus stretch the *chordæ vocales*. In all these figures ıe crecoid cartilage is designated by *a*, the thyroid cartilage by the arytenoid cartilages by *c*, and the epiglottis by *d*. The tter is represented turned upwards to show it more distinctly. ı Fig. 227 we see the glottis formed by the two lower *chordæ* ›*cales* stretched between the thyroid and the anytenoid cartilages. ı this figure we also see the upper *chordæ vocales*, together with ıe *ventriculi morgagni* lying between them and the lower *chordæ* ›*cales*.

The formation of notes in the larynx is quite similar to that of :ed-pipes. A tongue-work depends upon this principle, that a ody yielding on a blow, either no notes, or such only as are very ıint and soundless, may by continual impulses of the air create a ote corresponding to its length and elasticity. In the larynx the ibrations of the *chordæ vocales*, by which the glottis is closed and pened in rapid alternations, occasion the notes, as we may easily ee by the following contrivance made to imitate the larynx.

Cut a piece measuring about 1½ inches from a thin plate of aoutchouc (*gummi elasticum*), and let it be of sufficient breadth to e folded round a glass-tube about six or seven lines in diameter; ıy this so round the glass cylinder that one half may surround the ıtter, and the other half project beyond it; if we bring the two reshly cut edges of the caoutchouc together, they will adhere firmly, ınd thus obtain a caoutchouc cylinder fastened to, and projecting ›eyond the glass cylinder, to which it must be secured in the nanner represented in Fig. 229. If now we fasten the caoutchouc cylinder at its upper extremity to two separate points, pulling it apart, a chink will be formed (as seen in the figure) with caoutchouc edges, and if we blow into the pipe superiorly, we obtain a tone which is high in proportion to the force exerted by the lips. We may thus clearly see the vibrations of the two caoutchouc projections forming the chink.

FIG. 229.

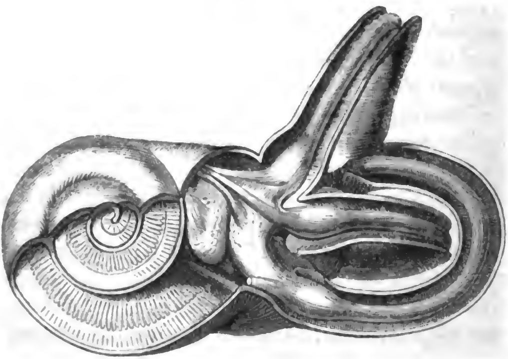
The height and depth of the tones of the larynx likewise depend upon the tension of the *chordæ vocales*.

The Organ of Hearing consists of three main parts: the outer :ar formed by the concha, and the external meatus, the cavity of the *tympanum* separated from the above meatus by the membrane of the *tympanum*, and the *labyrinth*. The labyrinth consists of

osseous cavities filled with a fluid, and through which the auditory nerve is distributed; in order to enable these nerves to act, the sound-vibrations of the fluid, which is wholly surrounded by bones, must be transmitted into the labyrinth; this is effected by two openings of the labyrinth leading into the *cavity of the tympanum;* they are termed the foramen ovale and the fenestra rotunda; the latter is covered with a tender membrane, while the former has a small bone inserted into it, by means of a membranous investment. This bone, which is termed the stapes, we are about to describe more fully.

Fig. 230 represents the labyrinth on an enlarged scale, and

FIG. 230.

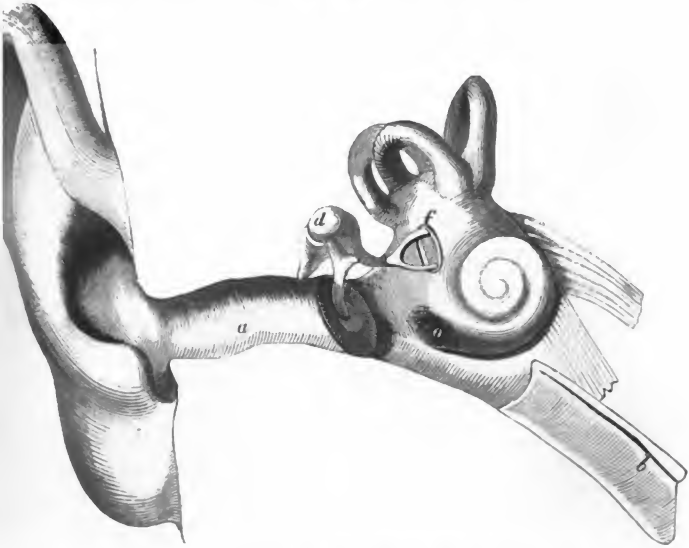


partly opened. It consists of three parts, the cochlea, the vestibule, and the semi-circular canals. The auditory nerve is distributed partly in the vestibule, where it rests on the ampullæ, the tubes lying in the semi-circular canals, and filled with a peculiar fluid, and more especially in fine ramifications to the cochlea. The convolutions of the cochlea are separated into two parts by a fine osseous partition-wall running parallel to one of these convolutions. This wall is very porous and cellular, and the former ramifications of the auditory nerve terminate in these cells, as may be seen in the exposed part of the cochlea in our figure.

The sound-vibrations are conveyed by means of the little bones in the cavity of the tympanum to the labyrinth. These bones are the malleus, which with its handle grows into the side of the membrane of the tympanum; the incus joining the malleus and connected with the stapes through the os orbicularis; the stapes

osing the foramen ovale. The relative position of all these irts may be seen in Fig. 231, representing the labyrinth on a very uch enlarged scale; *a* is the external meatus that conveys the

FIG. 231.



ound-waves from the concha to the membrane of the tympanum. his latter divides the cavity of the tympanum from the external ieatus. The tympanic cavity is connected by the Eustachian ibe *b* with the cavity of the mouth, by which means the air in the ırmer cavity can always be in equilibrium with the external air; is the malleus, growing into one side of the membrane of the mpanum, while on the other side it is inserted into the incus *e*; is the stapes, which as we see, closes the foramen ovale; *o* is the nestra rotunda; *n* is the auditory nerve distributed through the byrinth.

The separate parts of the organ of hearing do not lie so free as ight appear from Fig. 231; the osseous casing which encloses the hole being omitted for the sake of giving distinctness to the gure. The external meatus itself passes through the temporal one, the cavity of the tympanum is surrounded by osseous walls, id the labyrinth is formed in a part of the temporal bone, called, ı account of its hardness, the petrous portion, from which it can

only be separated with difficulty. In order to afford a correct idea of the separate parts of the organ of hearing, and the manner in which they grow in the osseous mass, we have given at Fig. 232 an actual anatomical section of the parts, represented according to their natural size; *a* is the section of the cochlea, *b* of one of the semi-circular canals, *n* the nerve, *i* the membrane of the tympanum, the malleus, incus, and stapes, are also clearly defined.

FIG. 232.

The concha serves to receive the air-waves and conduct them through the meatus to the membranes of the tympanum; the latter is thus put into vibrations which are transmitted through the ossicles and through the air in the cavity of the tympanum to the labyrinth. The membrane of the tympanum may be made more or less tense and drawn inwards by means of the muscle *t*; while by the muscle *s*, the stapes may be moved, and the intensity of the sound, therefore, considerably modified.

The most essential part of the organ of hearing is the *auditory nerve*; hence the membrane of the tympanum may be injured, and the series of the ossicles broken without the hearing wholly ceasing; in many of the lower animals, as in the crab, the organ of hearing consists merely of a vesicle filled with fluid, in which the vessel of hearing is distributed.

SECTION V.

INTRODUCTION.

OF LIGHT.

THE most casual observation teaches us that a *luminous point* ids its light in all directions; a burning taper, for instance, ced in the centre of a spherical surface would be visible from all nts of that surface; the same is the case with regard to a phos-rescent body, an electrical spark, &c. What is evident to our mon experience on a small scale, takes place alike in the vast anse of heaven. The sun sheds its light in all directions of ce; its light reaches simultaneously the earth and the other nets, the comets and all the other bodies of the firma-nt, be their position what it may in the boundless space of ven.

All luminous bodies consist essentially of ponderable matter; a *uum* may transmit, but it cannot engender light. All common lies admit of being divided into smaller and still smaller parti-s, and the ultimate physically perceptible atoms are termed *ninous points*. As every body is an assemblage of molecules or ms, so is a luminous body an assemblage of luminous points.

Bodies which are not self-luminous are divided into *opaque* wood, stones, metals; *transparent*, as air, water, glass; and *nslucent*, as thin paper and ground glass.

Opaque bodies do not suffer light to pass through their mass; t opacity always depends upon the thickness of the body, for all lies will admit of the passage of some degree of light if we ke them sufficiently thin. For instance, we may perceive a ish-green light through a thin gold leaf glued on a glass plate, we hold it to a taper, or up to the light.

Transparent bodies yield a passage to light, and allow of our seeing with distinctness the form of objects beyond them. Gases, fluids, and most crystallized bodies appear to be perfectly transparent when taken in small quantities; for in this case they seem to be wholly colourless, and not only admit of our seeing the form, but also the colour of objects: transparent bodies appear, however, to be coloured if they are thick—a proof that they must absorb some portion of light. A drop of water, for instance, appears wholly colourless, whilst the same fluid taken in a mass has a well-marked green hue.

Translucent bodies admit of the transmission of some portion of light, without, however, allowing the form or colour of objects being recognised. As long as a ray of light remains in the same medium, it advances in a straight line; but as soon as it comes in contact with another body, it is partly thrown back, *reflected* from its surface; it partly, however, enters the body, if it be transparent, in an altered direction, and is then *refracted.* We shall consider the subject of reflection and refraction more fully in a subsequent page.

The velocity with which light travels is so great, that it traverses all distances upon earth in an imperceptibly small space of time. By means of observations on the eclipses of Jupiter's satellites, astronomers have ascertained that light is transmitted with such velocity as to traverse the space between the sun and the earth in eight minutes and thirteen seconds, passing consequently over 195,000 English miles in one second. A cannon ball going at the rate of 1200 feet in a second would require fourteen years to go from the sun to the earth.

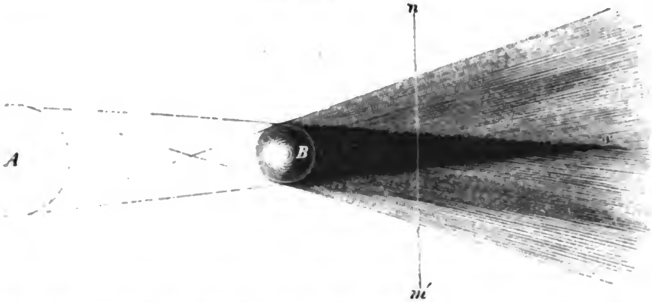
Shadows and half shadows.—A consequence of the straight transmission of light is, that a dark body exposed to rays of light, throws a shadow; if only lighted by a single luminous body, it is easy to define the shadow. The totality of all the lines issuing from the luminous point, and striking the dark body, forms a conical surface, and the part of it lying beyond the dark body forms the limits of the shadow.

FIG. 233.

If the luminous body have any considerable expansion, there will be a half *shadow* distinguishable beyond the true *shadow.* The shadow, which in this case is the central *shadow,* is the space receiving no light, the half shadow, on the contrary, is the

gregate of all the spots receiving light from some luminous

FIG. 234.



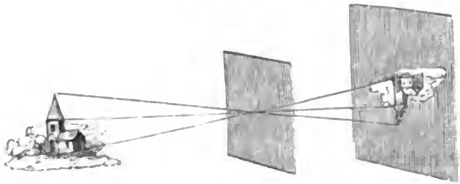
ints, but not from others. Let A (Fig. 234) be a large lumi-us sphere, B a small opaque one. The figure clearly shows the ent of the true shadow and the half-shadow. The shadow uld assume the appearance shown at Fig. 235, if received upon a screen m n. The diameter of the true shadow diminishes with the distance of the luminous body, while the diameter of the half shadow increases. The true shadow is, therefore, surrounded by a narrow half shadow, close to the shading bodies; close to the back of the shading body, the outline is somewhat sharply defined; an increased distance, the width of the half-shadow is more nsiderable, and the transition from the true shadow to the full ht on that account more gradual, while the shadow instead of ing sharply defined seems imperceptibly disappearing. Beyond point s, the true shadow entirely ceases, and the half shadow reasing continually in breadth, becomes on that account fainter d more undefined.

FIG. 235.

In this manner we may understand how the shadow of a body posed to the sun's light is sharply defined close behind it, while a greater distance it becomes quite undefined. Thus, for instance, cannot accurately mark the point where the shadow of the apex a steeple is lost upon the ground. A hair held up in the sun-ht close to a sheet of paper will cast a sharp shadow, while if held o inches above it, a shadow is scarcely to be observed. If now light issuing from a luminous point be thrown upon a screen, rough which a small aperture has been made, the light passing rough this opening will form a well defined ray; if we let this

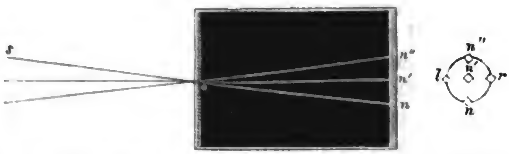
ray fall upon a second screen, we shall have a luminous spot upon a dark ground. In this manner we obtain on the wall of a perfectly dark room opposite to a minute aperture in the shutter, an image of an external luminous point, sending rays of light through the aperture into the chamber, and thus inverted images of all external objects may be thrown upon a wall, (Fig. 236). If we allow the

FIG. 236.



light of the sun to pass through a small opening, we shall at all times have a round image of the sun, let the shape of the opening be what it may. This at first sight apparently strange fact admits of a simple explanation. If the sun were a single luminous point, a light spot would be formed upon the wall opposite to the opening, and having precisely the form of that opening. If we assume that the opening *o* (Fig. 237) is quadrangular, the light passing from

FIG. 237.



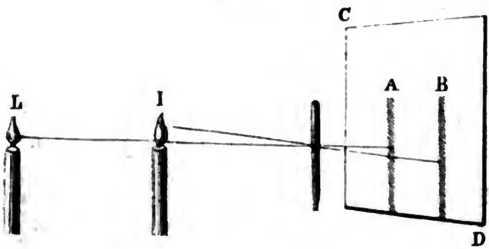
the highest point of the sun's disc will fall upon the screen in the direction *s o n*, while a small quadrangular light spot will appear at *n*. The lowest point of the sun occasions a quadrangular image at *n''*, while the middle point of the sun's disc forms the angular figure *n'*. The image *l* comes from the extremest point of the right limb of the sun, and *r* from the extreme point of the left. All the other points of the sun's limb give quadrangular figures, falling upon the circumference of the circle *l n'' r n*, whilst the remaining points of the sun illuminate the interior of this circle; the aggregate of all the separate quadrangular bright images forms consequently a circular illuminated spot.

The intensity of Light diminishes inversely as the square of the distance.—If we suppose a luminous point in the middle of a hollow sphere, its surface will receive all the light issuing from the point. If the same luminous point were in the middle of a hollow ball of two or three times as large a radius, the surfaces of this larger ball will receive all the light issuing from the point. But geometry teaches us that the surfaces of spheres are as the squares of their radii; if, therefore, the radii of a sphere are as $1:2:3$, the surfaces will be as $1:4:9$. Thus if the same luminous point be in a sphere of 2 or 3 times as great a radius, the same quantity of light must spread itself over a surface 4 or 9 times as great; the intensity of the light will consequently be 4 or 9 times less, if the illuminated surfaces be at 2 or 3 times as great a distance from the luminous point: that is to say, in general terms: *the intensity of light diminishes in proportion as the squares of the distances increase.*

This proposition is not strictly applicable to a luminous body of considerable surface, whose light is taken up from a small distance.

On this is based the comparison of the intensity of light yielded by different sources. In Fig. 238 *C D* represents a white wall.

FIG. 238.



Immediately before it there is placed an opaque rod somewhat thicker than a pencil; if now there be a light at *l* and another at *L*, two shadows of the rod will be seen upon the wall, one at *A*, the other at *B*.

The part of the wall free from shadow is lighted by *l* and *L*, while the shadow *A* is only illuminated by the light *l* and *B* by the light *L*. If now both sources of light are precisely alike, both

shadows will appear equally dark, provided the two lights are at equal distances. But if L yield more light at an equal distance, the shadow B will be less dark than A, and in order to make both shadows alike, it would be necessary to remove L further from the screen.

If we assume that L were really so far removed that both shadows were again made equal, the intensity of light yielded by the two flames would be as the squares of their distances from the screen; if, therefore, L were two or three times further from the screen than l, the intensity of light from L would be four or nine times as great as that of l.

CHAPTER I.

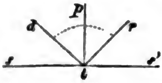
REFLECTION OF LIGHT.

Reflection of light from smooth surfaces.—If we let a ray of sun-light enter a darkened room, and fall upon a polished metallic surface, we generally notice the two following phenomena:—1. We observe a ray which seems to have come in a certain direction from the mirror, forming a little image of the sun upon the objects with which it comes in contact, as if a direct sunbeam had struck the spot; such rays are regularly reflected, and the intensity of their light is more considerable in proportion as the mirror is well polished; 2. From different parts of the dark room, we may distinguish that part of the mirror which is struck by the incident sunbeam; this arises from a portion of the incident light being *irregularly reflected:* that is, scattered in all directions from the incident sunbeam. The intensity of the scattered light is greater in proportion as the mirror is imperfectly polished.

If there were absolutely smooth reflecting surfaces, we should not be able to perceive them by our eyes, for bodies are only rendered perceptible from a distance by the rays scattered upon their surfaces. Regularly reflected rays show us the images of the luminous point whence they originate, but not the reflecting body. In a very good mirror we scarcely perceive the reflecting surface intervening between us and the images it shows us.

We will now proceed to determine the direction of regularly ẟlected rays. In Fig. 239, if $r\ i$ be the direction of the incident ray, and $i\ p$ a perpendicular drawn from the surface of the mirror; the ray will be reflected in such a direction $i\ d$ that the angle of reflection $d\,i\,p$ is equal to the angle of incidence $r\,i\,p$; the ray, therefore, makes before and after its lection the same angle with the perpendicular: farther, the :ident ray, the perpendicular and the reflected ray, all lie in e same plane.

FIG. 239.



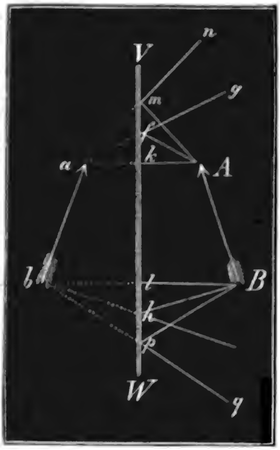
By the help of these principles we may easily prove that a ıne mirror must show the images of objects lying before its ıooth surface, and that the images and object must be symmecal in relation to the reflecting plane.

Let $m'm$ (Fig. 240) be a smooth mirror, l a luminous point before it, and throwing a ray $l\ i$ upon it. This ray is now reflected in the direction $i\ c$, in accordance with known laws, and if the reflected ray impinge upon the eye, it will produce the same effect as if it came from a point behind the mirror, lying upon the prolongation of $c\ i$, and at a stance from the eye equal to the space the ray must really averse from l to i, and from thence to the eye; we there-re find this point l', by prolonging $c\ i$ and making $i\ l' = i\ l$. now we join l and l' by a straight line, we may easily show ıat the triangles $l\ i\ k$ and $l'\ i\ k$, are equal to one another, and ıence it further follows that $l\ l'$ is at right angles to $m\ m'$, ıd that $l\ k = l'\ k$. *In order, therefore, to find the image of a minous point on a smooth mirror, it is only necessary to let fall perpendicular from the luminous point on the mirror, or on its rolongation, and to prolong it as far behind the surface of the irror as the luminous point lies before it.*

FIG. 240.

As this applies to any point of a body emitting light, whether ıat light be its own, or scattered rays, we may easily construct ıe image of an object. Let $V\ W$ be a plane mirror (Fig. 241), B an arrow lying before it: we shall find the image of the oint, if we let fall a perpendicular $A\ k$ from A to the surface f the mirror, and make its prolongation $a\ k$ equal to $A\ k$; all ıe rays passing from A appear to diverge after reflection as

FIG. 241.



if they came from a; a is therefore the image of A; in the same way it follows that b must be the image of B; the appearance of the figure shows clearly that both the image and the object are symmetrical in relation to the surface of the mirror.

The direction of the reflected light may, therefore, be determined with geometrical exactitude; but this is not the case with respect to the intensity of the reflected rays.

In general the following holds good:

1. The intensity of regularly reflected light increases with the angle of incidence, without, however, being null at rectangular incidence.

2. It depends upon the medium in which the light moves, and against which it impinges.

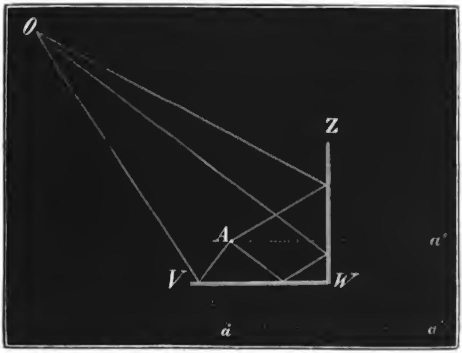
We will here adduce a few examples for the sake of making the matter clearer.

If the rays passing from the flame of a taper fall nearly at right angles on a plate of ground glass, we are unable to distinguish any image of the flame, but perceive it plainly when the rays fall upon the glass obliquely; in this case we may also see the image on polished wood, shining coloured paper, &c.; whence it follows that the quantity of reflected light is increased in proportion with the obliquity of the rays.

Angles of reflection.—If two mirrors be placed together at any angle, we see many images of the objects intervening between them, their number depending upon the inclination of the mirrors. Let $V W$ and $Z W$, in Fig. 242, be two plain mirrors, meeting at right angles; and A, a luminous point within the angle formed by them. In the first place an image of A will be seen in each mirror, appearing in the one at a, and in the other at a'; an eye at O will see besides the object A, the images a and a' reflected from A by a single reflection. But all rays reflected from one mirror may fall upon the other mirror, and suffer reflection from the latter. As all the rays reflected from the first mirror diverge as if they came from a, a is to some extent an object which sends rays to the mirror $Z W$,

and we may consequently easily find the reflected image of a in the mirror $Z\,W$; let us now let fall a perpendicular from a on the

FIG. 242.



prolongation of $Z\,W$, producing it in the manner already indicated, when we obtain the image a'', from which all the rays appear to emanate, which are reflected from the mirror $V\,W$ to the mirror $Z\,W$, where they undergo a single reflection; and thus the eye at O perceives another image at a'' after a second reflection.

But the image a is an object for the mirror $V\,W$, and if we determine the situation of the image of a', we find that it is likewise a''; that is, all the rays reflected from $Z\,W$ upon the mirror $V\,W$, diverge after the second reflection as if they came from a''.

The rays reflected a second time do not fall upon either of the mirrors; or in other words, no further image of a'' is visible; we therefore see, besides the object A in this case, three images of it.

If the mirrors had inclined at an angle of 60^0, 45^0, or 36^0, that is, if the angle they made amounted to the $\frac{1}{6}$, $\frac{1}{8}$, or $\frac{1}{10}$ of the whole circumference, we should have, inclusive of the object itself, 6, 8, or 10 images.

Upon this principle rests the construction of the *kaleidoscope*.

As we have seen, the number of the images increases if the angle be diminished; their number becomes infinitely great if the angle of the mirrors be null; that is if the mirrors be parallel to each other.

Reflection from curved mirrors.—If a ray of light fall upon a curved surface at any point, it will be reflected exactly as if it had

fallen upon the plane tangent to this point. A luminous point which is placed in the centre of a polished sphere, therefore, will send rays of light to all points of the spherical surface, which will be all thrown back collectively to the centre.

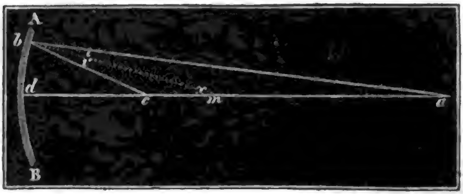
If we take a hollow sphere, whose inner surface is well polished, then a piece cut from this sphere by a plane forms a *concave spherical mirror*; while a convex spherical mirror is a section of a sphere polished externally.

FIG. 243.

The diameter of a spherical mirror is the line *m m′*, Fig. 243, connecting two opposite points of the edge; the line *c a*, connecting the middle point of the sphere with the middle of the mirror, is termed its axis; and the angle formed by the lines *c m* and *c m′*, its aperture. The central point *c* of the sphere, of which the mirror is a part, is also called the centre of curvature.

Of concave spherical mirrors.—Let *A B*, Fig. 244, be the section

FIG. 244.



of a spherical concave mirror, whose centre is *m*. Let *a* be a luminous point, throwing its rays upon the mirror. If now we draw a straight line *a m d* from the point *a* through the centre of the sphere to the mirror, this line will be the axis of the coal pencil of rays reflected by the mirror. It is easy to find how a ray *a b* of this pencil of rays is reflected from the mirror, for the straight line drawn from *b* to the focus *m* is the perpendicular at the point of incidence. If we make the angle $i =$ to the angle i', *b c* is the reflected ray.

If we suppose a circle to be drawn upon the mirror, whose points are all as far from *d* as *b*, it is easy to see that all rays emitted from *a*, and striking the mirror at any point of this circle, are so reflected that they cut the axis *a d* in the same point *c*.

If the luminous point be very far removed, we may consider all the rays it throws upon the mirror as parallel to each other.

Let us determine the position of the point c for this case. In Fig. 245 let $a\,b$ be an incident ray of light parallel to the axis; $b\,m$ the perpendicular at the point of incidence; then it is evident that $i = x$. If now the angles i and x are very small, the angle $b\,c\,m$ is so obtuse that the sum of the sides $b\,c$ and $c\,m$ is not much greater than the radius $b\,m$, and since $b\,c = c\,m$, $c\,m$ is very nearly equal to $\frac{1}{2}\,b\,m$, that is, almost equal to half the radius; we may therefore assume without any serious error that rays parallel with the axis, falling upon the mirror in such points b that the arc $b\,d$ embraces but a small angle, meet at one point of the axis, lying equi-distant between the centre of the mirror and the mirror itself. Rays lying so near the axis that the value of $m\,c$ does not differ materially from $\frac{1}{2}\,m\,b$ are termed *central rays.* The point of union of the parallel and central incident rays bears the name of the principal focus. (It will be marked F in the following figures.) *This focus lies, as we have seen, equi-distant between the centre of the mirror and the mirror itself, upon the axis of the parallel rays.*

FIG. 245.

FIG. 246.

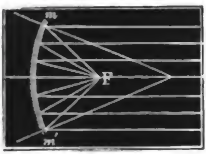
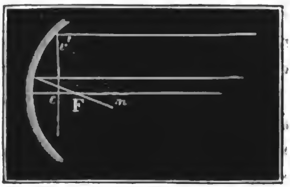


FIG. 247.



The more the angle i increases, that is, the further the rays fall from the axis of the mirror, the greater is the curvature of the mirror from the point of incidence to its centre, and the more the point c, in which the reflected rays cut the axis, approaches the mirror. The point of union of the rays that are not central lies, therefore, nearer to the mirror itself than the principal focus, as may be seen from the Fig. 247.

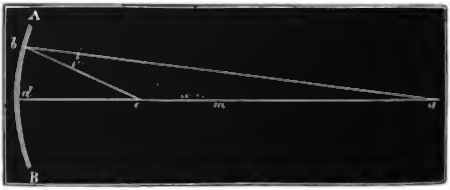
In order to make a concave mirror applicable to optical purposes, the rays emitted from one point must re-unite as nearly as possible in another single point. This, however, is only possible

if the aperture of the mirror be inconsiderable, not exceeding, at most, 8 to 10°; for in that case we may consider all the rays falling upon the mirror as central rays. We will confine ourselves to the consideration of such mirrors, and consequently of central rays only.

The above mentioned fault that all rays falling parallel with the axis are not united exactly in one point is termed *spherical aberration*.

If the luminous point is not at an unreasonable distance, but simply such a one that we cannot neglect the divergency of the rays falling upon the mirror the focus will change its position, departing more and more from the mirror the nearer the luminous point approaches it. That such is the case may easily be seen from Fig. 248. The nearer the luminous point is, the smaller

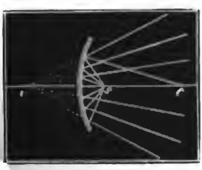
FIG. 248.



will be the angle i to the same point b of the mirror, the smaller also will be the angle i', and the more c will move towards m. If, therefore, a luminous point constantly approaches the mirror, from which it was so far removed that its rays were again concentrated in the principal focus, the focus will continue to recede from the principal focus, approaching the central point, until at last, when the luminous point is in the centre of the mirror, the focus coincides with it. If the luminous point approach still nearer to the mirror, the focus falls farther and farther from the mirror; and if it arrives at the principal focus, its rays will be reflected from the mirror parallel with the axis.

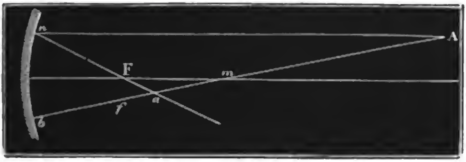
Fig. 249 represents the only remaining case, namely that of the luminous point s lying between the mirror and the principal focus. Here the rays are so reflected that they diverge after the reflection as if they had come from a point v lying behind the mirror, and which may easily be found by construction for any given case.

FIG. 249.



We have hitherto considered only such luminous points as lie on the axis of the mirror, where, consequently, the axis of the rays thrown upon the mirror coincides with the axis of the mirror itself. All the laws we have hitherto developed apply, however, equally to such luminous points as lie out of the axis of the mirror; let *A* be such a luminous point in Fig. 250. If

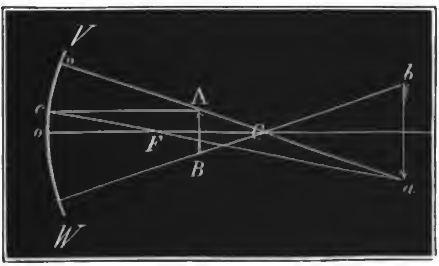
FIG. 250.



we draw a line from *A* through *m* to the mirror, this is the axis of the conical pencil of rays cast on the mirror, and on this axis all the rays emanating from *A* must again unite. If a whole pencil of rays fell parallel to *A m b* upon the mirror, they would re-unite after reflection in the point *f*, lying half way between *m* and *b*; as, however, the rays coming from *A* diverge, their point of re-union will lie further from the mirror than *f*. We may easily find this point of union by construction. Let us draw a line *A n* from *A* parallel with the axis of the mirror. A ray falling upon the mirror in this direction will evidently be reflected towards the principal focus *F*; if now we draw a line from *n* through *F*, this line will cut the line *A m b*, the point of intersection *a* is clearly that in which all the rays coming from *A* are again united after their reflection by the mirror : in short *a* is the image of *A*.

Of the images produced by concave mirrors.—In Fig. 251 let

FIG. 251.



A B represent an object lying between the centre of curvature *C* of the mirror, and the principal focus *F*. From what has been already said, it is easy to find the image of the point *A* as it lies upon the line drawn through *C* and *A*, since a ray *A n* is reflected in the direction *n A*. A ray *A e* falling from a parallel to the main axis on the mirror, will, however, be reflected by the principal focus *F*. The rays reflected in the directions *n A* and *e F* intersect each other at *a*, and here is the image of *A*. In like manner, we can find the image *b* of the point *B*, and thus we see, *that by means of a concave mirror, we may obtain beyond C an inverted and enlarged image of an object A B lying between the principal focal point and the centre of curvature.*

As the rays issuing from *A* are united at *a*, so conversely, if *a* were a luminous point, the rays issuing from it would be reflected by the mirror at *A*; in short *A* is in this case the image of *a*; in like manner *B* is the image of *b*. *If, therefore, an object* a b *be beyond the centre* C, *the concave mirror will give an inverted and diminished image between the centre* C *and the principal focal point* F.

The images we have been considering are essentially different from those yielded by plane mirrors. All rays emitted from a luminous point are reflected from a plane mirror in such a direction as if they came from a point behind the mirror, consequently they diverge. In the cases above considered, however, the rays issuing from any point of the object are actually again collected by means of the mirror in one point; we will, therefore, for the sake of distinction call these images convergent *images*. They may be received on a screen of white paper or ground glass, and an image may be thus obtained exactly resembling the object in all its relations; the points of the screen strongly illuminated by the concentration of the rays scatter the light in all directions, and the image is then still visible if the rays reflected from the mirror do not come direct to the eye.

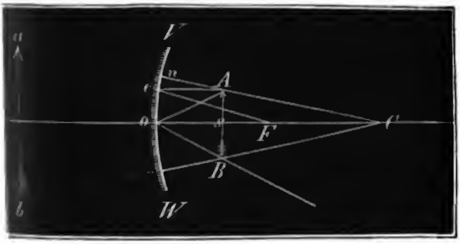
The further the object is moved from the concave mirror, the more the image must approach the principal focal point, as may easily be understood; the image of the immeasurably remote sun must therefore lie in this focal point, if the axis of the mirror be directed towards the sun. If the sun-beams fall obliquely, and consequently not in the direction of the axis of the mirror, the image will of course no longer be in the axis, but to the side of it, its distance from the mirror being, however, always equal to half

radius of curvature of the latter. As the sun appears to us at angle of about 30′, the image of the sun seen from C must ›ear at the same angle; its absolute size depending consequently ›n the radius of curvature of the mirror. For instance in the us of Herschel's large reflector, whose radius of curvature is 50 t, the sun's image is about 3 inches in diameter; the diameter the sun's image is about 3 millimetres if the radius of ·vature of the mirror be 1 metre.

In order to find the radius of curvature of a concave mirror, we :d only measure the distance at which the sun's image lies from : mirror, since twice this distance is equal to the radius of ·vature required. The images of such objects as are removed ›re than 100 times the length of the radius of curvature from : mirror are extremely near the focus itself.

We have still to ascertain the position of an image for the case ıere the object lies between the mirror and the focus. We have :n, that all rays emanating from a luminous point that is nearer the concave mirror than is the principal focal point, are reflected if they came from a point behind the mirror; in the case we are out to consider, there cannot therefore arise any combined nvergent image.

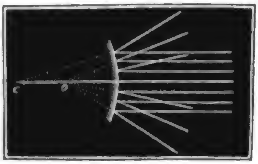
FIG. 252.



Let $A B$, Fig. 252, be the object whose image we would seek. The ray $A\ n$ falling at right angles upon the mirror is reflected in the direction $n\ A\ C$, while the ray $A\ e$, which rikes the mirror in a direction parallel to its axis, will be thrown ıck towards the principal focal point F; the rays $n\ A\ C$ and $e\ F$ › not however coincide, but their directions intersect each other :hind the mirror at a, if prolonged sufficiently backwards; and ıis point a is the image of A. In like manner, the image b of the ›int B may be found; *if therefore the object lie between the focus ıd the mirror, a magnified and erect image will fall behind the irror;* it is therefore precisely the same as images of plane ıirrors, with the exception of the enlargement of the image.

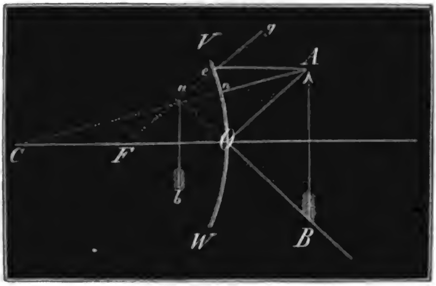
Convex mirrors have no actual, but merely an imaginary, or as it is commonly termed, a virtual focus, that is to say, the rays incident upon them are not united at one point, but diverge, after reflection, in such a manner as if they had come from a point behind the mirror. If rays parallel to the axis fall upon convex mirrors, their imaginary focus will be half way between the mirror and the centre *c*. It is consequently easy to construct the images obtained by these mirrors.

FIG. 253.



Let *V W* be a convex mirror, Fig. 254, *A B* an object before it. A ray *A n* falling at right angles to the mirror will be reflected in the direction *n A*, while the ray *A e* parallel to the axis will be reflected in the direction *e g*, as if it came from the vertical principal focus *F*. If we prolong *e g* and *n A* backwards, these will cut each other behind the mirror at *a*; here therefore is the image of *A*, that is to say, all rays emitted from *A* are reflected by the convex mirror, as if they came from *a*.

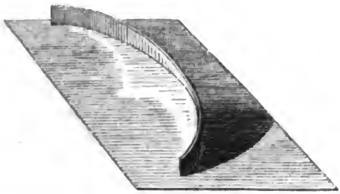
FIG. 254.



After we have found the image *b* of the point of *B*, we shall easily perceive that we obtain *in convex mirrors diminished erect images behind the mirror.*

Of the focal lines or caustics.—Although the rays of light emitted from a luminous point do not unite again in the same point after their reflection from a curved surface, every two adjacent reflected rays will always intersect each other; all points of intersection of two adjacent rays reflected in the same plane yield a curved line, termed *the focal, or caustic line,* and their nature depends upon the nature of the reflecting surface. All caustic lines produced by a reflecting curved surface, form, when taken collectively, a curved surface termed *a caustic surface.* Near this

FIG. 255



the intensity of the light is the greatest, as we may see by the heart-shaped line forming itself within a cylindrical vessel or a ring, when either is lighted by the rays of the sun or of a flame. Fig. 255 shows a focal line of this kind formed by a curved reflecting strip of steel.

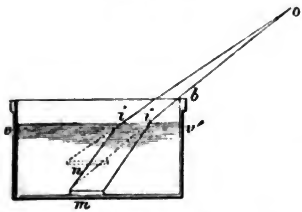
CHAPTER II.

DIOPTRICS, OR THE REFRACTION OF LIGHT.

By *refraction* we mean the deviation, or change of direction suffered by a ray of light in passing from one medium to another. The following experiment will convince us of the actual occurrence of such a change in direction.

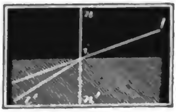
Let us lay a piece of money, or a piece of metal, *m* at the bottom of a vessel *v v′*, Fig. 256, and direct the eye *o* in such a manner as to see merely the edge of the object, while the rest of it appears covered by the rim *b* of the vessel. If now water be poured into the vessel, the piece of money will appear to rise more and more, and as the level of the water rises in the vessel, the whole piece of money will at last become visible, appearing to lie at *n*, although in the meantime, neither the object nor the eye have changed their positions. The light no longer comes in a straight line from *m* to *o*, but describes the broken line *m i o*.

FIG. 256.



The angle of incidence in refraction as in reflection is the angle, which the incident ray *l i*, Fig. 257, makes with the perpendicular *i n* let fall at the point of incidence.

FIG. 257.



The angle of refraction is that angle made by the refracted ray *i r* with the prolongation *i n'* of the perpendicular at the point of incidence.

The plane of incidence is that which passes through the incident ray, and the perpendicular at the point of incidence; *the plane of refraction* passes through the refracted ray and the above perpendicular.

The plane of refraction corresponds with the plane of incidence, but the following relations exist between the angle of incidence and the angle of refraction.

Let *l b*, Fig. 258, be a ray of light falling upon a surface of water, and *b f* the corresponding refracted ray. If we now suppose a circle to be drawn around *b*, it will intersect the incident ray at *a*, and the refracted ray at *f*; and letting fall a perpendicular *a d* from *a*, and another *f d'* from *f* on the perpendicular at the point of incidence then *f d*, will be $\frac{3}{4}$ of *a d*.

FIG. 258.

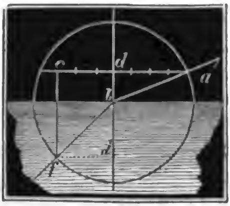
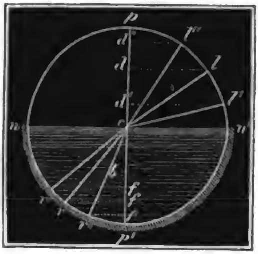


FIG. 259.



The same relation always exists in the passage of a ray of light from the air into water between the direction of the incident and the refracted ray. If in Fig 259 the incident ray *l c* were refracted towards *c r'*, *l c* towards *c r*, and *l' c* towards *c r''*, then $r'' f'' = \frac{3}{4}\, l'' d'$, $r f = \frac{3}{4}\, l d$ and $r' f' = \frac{3}{4}\, l' d'$.

If the radius of the circle, Fig. 259, be $= 1$, we call the above-mentioned perpendicular the *sine* of the corresponding angle; $l' d'$ is the sine of the angle $l' c p$; $l d = sin.\ l c p$; $l'' d'' = sin.\ l'' c p$; in the same manner $r' f = sin.\ r' c p'$; $r f = sin.\ r c p'$; $r'' f'' = sin.\ r'' c p'$.

By the introduction of this designation, the law of refraction for the passage of rays of light from air to water may be simply expressed as follows:

The sine of the angle of refraction is always $\frac{3}{4}$ of the sine of the corresponding angle of incidence.

In their passage from the air to glass, rays of light undergo nore decided deviation; for in this case the sine of the angle refraction is about $\frac{2}{3}$ of the sine of the angle of inci-nce.

The relation in which the sine of the angle of refraction stands the sine of the angle of incidence is for every substance different; is relation is designated by the term of the index, or exponent refraction. The value of the index of refraction is for:

Water . . .	$\frac{4}{3}$
Glass . . .	$\frac{3}{2}$
Diamond . . .	$\frac{5}{2}$.

In the transition of light from the air to the diamond, the ne of the angle of incidence is consequently $2\frac{1}{2}$ times greater an the sine of the angle of refraction; in the diamond, therefore, ie rays of light suffer a very considerable deviation. The amond is a highly refracting substance.

Refraction of light in prisms.—A prism is a term applied in ptics to a transparent medium, bounded by two surfaces inclining wards each other.

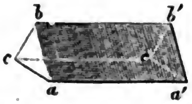
The *edge* of the prism is the line in which the two bounding urfaces intersect, or would intersect each other, if they were ıfficiently extended.

The base of a prism is any one of the surfaces opposite to one f the refracting edges, whether it actually exist or is only naginary.

The refracting angle is the angle made by the two surfaces of he prism.

The principal section is the section of the prism by a plane at ight angles to one of its edges.

FIG. 260.



The prisms generally made use of, are such as are bounded by rectangular surfaces *a b a' b'*, *b c b' c'*, and *c a c' a*. If light pass through the surfaces *a b'* and *a c'*, *a a'* is the refracting edge, and the surface *b c'* he base; *b b'* is the refracting edge if the ray of light pass the urface *b a'* and *b c'*.

The principal section of such a prism is a triangle, and according is this latter is rectangular, isoceles or equilateral, the prism is rectangular, isoceles, or equilateral.

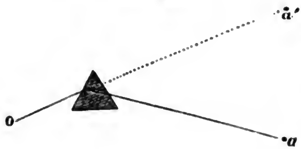
FIG. 261.

The prisms are usually fastened to a brass stand (Fig. 261).

By pushing the rod *t* up or down the tube in which it is inserted, the prism may be raised or lowered, and by means of the joint at *g* it may be inclined in any direction.

If we hold a prism in such a manner that the refracting edge is directed upwards, we observe on looking through it two remarkable phenomena: in the first place, all objects appear to be considerably displaced from the position they actually occupy, and so much raised that the eye at *o* (Fig. 262) sees the object *a* through the prism at *a'*; and secondly, they appear to have coloured edges. If the refracting edge were directed downwards, all objects seen through the prism would seem to be removed downwards out of their right place. A vertical prism displaces objects to the right or left according to the side to which the refracting edge is turned.

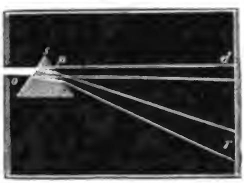
FIG. 262.



By altering the experiments in this manner, we shall easily be convinced that all objects seen through the prism appear removed towards the direction of the refracting edge.

If a ray of sun-light enter a dark room through a small opening in the direction *v d*, and be received upon a prism, we shall observe a deviation and a colouring. If the prism is in an horizontal position, and its refracting edge turned upward, instead of the white round image of the sun, which would appear without the prism at *d*, we perceive an oval image coloured with the hues of the rainbow, the *solar spectrum*, at *r*. If the refracting margin were directed downwards, the prismatic solar image would appear above *d*. By a vertical prism, the sun's image would deviate to the right or left according to the position of the former.

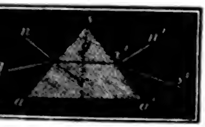
FIG. 263.



These phenomena of colour will be subsequently considered, we all at present only speak of the deviation.

The above-mentioned phenomena admit of easy explanation.

FIG. 264.



Let *a s* (Fig. 264) be the first, and *a′ s* the second surface of a glass prism; *l i* the incident, *i i′* the refracted, and *i′ e* the emergent ray. On its passage from the air into the glass, the incident ray is refracted and brought nearer to the perpendicular at the point of incidence *i n*; having ached the second surfaces, it is again refracted, but removed rther from the perpendicular *i′ n′* on its transition into the air.

A prism will, other circumstances being the same, cause rays light to deviate in proportion to the magnitude of the refracting gle. If this angle be 60°, the deviation will be more considerable than with one of only 45°.

A prism consisting of a strongly refracting substance causes e rays of light to deviate more considerably than a likeaped prism of a less powerfully refracting substance. In a ism of water, the deviation is less considerable than in one of ass.

In the same prism the amount of deviation varies according the direction in which the rays of light are incident upon the st surface.

On looking at an object through a prism, we see how the image moves further from the position of the object, and then again aws nearer to it as we turn the prism on its axis. The smallest viation occurs in the case where the rays traverse the prism mmetrically, as seen in Fig. 264. If the direction of the incident y were changed to one side or the other, the deviation would crease.

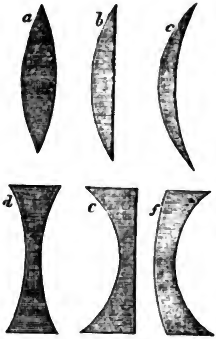
In order to make prisms of liquids, hollow prisms are used, ving their lateral sides formed of glass-plates.

Refraction of light by lenses.—The term *lens* is applied to ansparent bodies possessing the property of increasing or minishing the convergency of the rays that pass through them.

We shall here only treat of *spherical lenses*, that is, such as have eir bounding surfaces composed merely of portions of spherical rfaces and planes, since these alone are applied to optical struments. There are also *elliptical, parabolic, cylindrical,* and her lenses, exhibiting phenomena similar to the spherical.

There are six different kinds of lenses, sections of which are represented at Fig. 265. *a* is a *bi-convex* lens, the one that is bounded by two externally convex spherical surfaces. The plane-convex lens *b* is bounded by one plane and one convex surface.

FIG. 265.



The concave-convex lenses, bounded by one convex and one concave surface, as *c* and *f*, are also termed *Meniscus lenses;* they are divided into two kinds, according as the degree of curvature of the concave surface is the lesser of the two as at *c*, or the greater as at *f*. *d* represents a *bi-concave* lens, *e* one that is *plano-concave.*

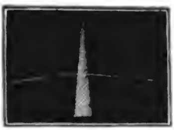
The three former, *a*, *b*, and *c*, are thicker at the centre than at the edges, and are termed convergent lenses. The three latter, *d*, *e* and *f*, which are thinner in the middle than at the edges are termed divergent *lenses.*

The axis of a lens is the straight line uniting the centre of both the spherical surfaces, by which the lens is formed. In plano-concave and plano-convex lenses, the axis is the perpendicular passing from the centre of curvature to the plane.

In order to develope the most important propositions concerning the refraction of light by lenses, we must once more return to prisms, and consider more attentively the case where the refracting angle of the prism is very small.

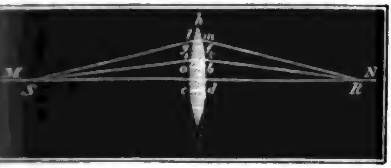
In a prism of small refracting angle, as in Fig. 266, the deviations may, without any serious error, be considered proportional to the refracting angle. A prism whose refracting angle is twice as great as that in Fig. 266, would produce twice as much deviation; and if the angle were only half the size of the one in Fig. 266, the deviation would only be half as great.

FIG. 266.



In Fig. 267 *a b c d* is an elongated rhomb, to which is joined above a parallel trapersium *a b g f* and below, a like figure; the triangle *f g h* is therefore found above, and one precisely like it below. The two sides of the parallel trapezium, which are not parallel to each other, form, when prolonged, the isosceles triangle

FIG. 267.



with an angle at the apex, which must be half as large as the angle at the apex of the upper triangle at *h*.

If we suppose the whole figure turned round the s *M N*, there will arise a lens-like body, composed of many ıes. The middle of this will be a plane disc.

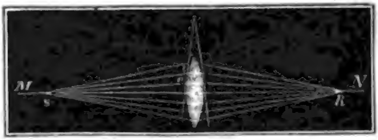
If now rays of light coming from one point of the axis *M N* ›et this zone-system, we may determine the deviation suffered the rays of light in each of these zones, according to the laws of refraction of light in prisms.

Let the point *S* lie so that a ray of light coming from it, and ›eting the surface *a g* in *i*, may experience the minimum of viation in its passage through *a b g f*, then the emergent ray ll be symmetrical with the incident ray, intersecting the axis a point *R*, as far from the lens as *S*.

A ray of light undergoing the minimum of deviation in the angle *h f g*, is turned twice as far from its original direction in *f g a d*, because the refracting angle of the upper prism twice as large as that of the lower one. Such a ray of light, ffering the minimum of deviation in the upper triangle, passes rough the latter in the direction *l m*, which is parallel to e axis *M N*; the incident ray as well as the emergent one will, wever, necessarily make twice as large an angle as the incident d emergent rays corresponding to the minimum of deviation *a b f g*; if, therefore, a ray *S o* pass from *S*, making twice large an angle with *M N* at *S i*, it will be at the minimum deviation in *f g h*, and, going symmetrically from the other le, will be refracted towards *R*. The ray *S l m R* passes through e lens at twice the distance from the axis as the ray *S i k R*, ıich undergoes only half as great a degree of deviation.

If we suppose the broken lines *d b f h* and *c a g h* of the rmer figures to be replaced by circular arcs, whose centres upon the axis *M N*, we shall have a regular lens, Fig. 267, stead of the lens-like body we have been considering, and a ray light falling upon the lens at any spot, as at *a*, will be refracted actly as if it had fallen upon a prism, whose diagonal section obtain by drawing tangents to the circular arcs at *a* and the ›ints opposite.

FIG. 268.



If we were to draw tangents on both sides from a second point *b*, twice as far from the axis as *a* is, these tangents would intersect each other at an angle twice as large as the angle at which the tangents drawn from *a* intersect each other. If now a ray of light pass through the lens *a* parallel to the axis, it will make equal angles with the axis on its entrance, and after its leaving the lens, intersecting the axis at the points *S* and *R*, which are equidistant on either side from the lens. If now a second ray of light pass from *S*, meeting the lens at *b*, it will experience twice as great a deviation as at *a*, and on that account will likewise be refracted towards *R*. A ray of light passing from *S*, and falling upon the lens at *c*, which is three times as far from the axis as *a*, will experience three times the amount of deviation that the rays incident at *a* undergo, and which are therefore refracted towards the same point *R*.

What has been said of *a*, *b* and *c* applies equally to the intervening points; in such a lens as is represented at Fig. 268, there is a point *S* upon the axis, having the property that all rays coming from it and meeting the lens are concentrated by the latter in one and the same point *R*, which lies as far from the lens on the other side as *S*.

These statements apply, however, only where the curvature of the lens from the centre towards the edges is inconsiderable, for in that case only is the inclination of the tangents proportionate to the distance of these points of contact from the axis. In the lenses of which we are now about to speak, the curvature from the middle towards the edges is inconsiderable.

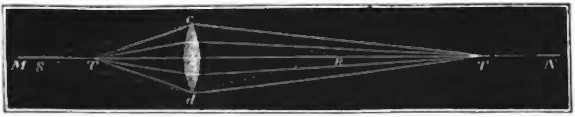
As long as the angle at which the incident ray fall upon a prism of small refracting angle does not deviate much from a right angle; as long, therefore, as the rays meet the prisms nearly in the direction corresponding to the minimum of deviation, the deviation produced by the prism will not differ materially from the minimum degree.

This likewise applies to lenses. If the lens, Fig. 268, meet a ray of light at *c*, the direction of which does not deviate to any great extent from the direction *S c*, the deviation experienced

by refraction in the lens will be the same as that experienced by the ray $S\,c$.

In Fig. 269, let S be that point of the axis $M\ N$, whose rays,

FIG. 269.



meeting the lens, traverse it symmetrically and are united on the other side in a point R as far distant from the lens as S. The ray $S\,c$ which falls upon the lens near its margin is refracted in the direction $c\,R$, the incident and the refracting ray making the angle $S\,c\,R$.

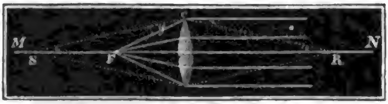
If now a ray of light coming from T instead of S fall upon the lens at a, the ray $T\,c$ would, from what has been said, experience as great a deviation as $S\,c$; we should therefore ascertain the direction of the ray after its leaving the lens, by drawing the line $c\,T'$ in such a manner that the angle $T\,c\,T'$ should be equal to the angle $S\,c\,R$, or in other words, we must make with $c\,R$ an angle $R\,c\,T$ which shall be equal to the angle formed by $T\,c$ and $S\,c$.

But the ray $T\,d$ proceeding from T is refracted after leaving that point of the axis, and falls upon the lower border of the lens: in fact all rays coming from T falling upon the lens meet at T', for in the same proportion in which the incident rays approach the axis, they deviate less, and hence unite together in T'; so long, at any rate, as the angle which the external incident rays make with the axis does not exceed certain bounds; (that is to say, does not become so large that we can no longer without marked error consider the angles proportional to their tangents.)

If, therefore, the luminous point approach the lens from S, the point of union of the rays will recede further from the lens to the other side; the more T approaches, the further T' will recede; the latter recedes much more rapidly, however, than the former approaches.

Let us now examine how rays coming from a point F of the axis are refracted by the lens, Fig. 270. F being so situated that $F\,c = F\,S$. In this case, the angle $o = y = z$. But now the

FIG 270.



ray $F c$ is so refracted by the lens, that the angle x made by the emergent ray with $c R$ is equal to y; consequently $x = z$, and hence it follows that the ray $F c$ is so refracted by the lens, that it runs parallel to the axis.

The same applies to all the other rays coming from F, and falling upon the lens. They come out as a pencil of rays parallel with the axis.

If, as can be done in most cases, we disregard the thickness of the lens with respect to the distances of the points S and F from it, we may say, that the point F lies in the centre between S and the lens.

If, therefore, a luminous point from S beyond the lens be brought nearer to the latter, the point of union on the other side of the lens will recede, and if the luminous point advance to F, the point of union will be indefinitely distant; the rays emerge parallel with the axis.

But if, conversely, rays fall upon the lens from a point lying at an indefinite distance upon the axis, or in other words, if a pencil of rays parallel with the axis falls upon the lens, they are united by the lens at F. This point of union F of incident rays parallel with the axis is named the *principal focal point*.

If the luminous point approach towards the lens from this indefinite distance, the point of union will recede on the other side of the lens; if the luminous point be at T', Fig. 269, the point of union will be at T, if the luminous point approach as near as R, the point of union will be at S, if it approach so near to the lens as to stand midway between it and R; that is to say, if it approach to the *focal distance*, the rays will be parallel with the axis after their passage through the lens.

The *Focal distance*, that is the distance of the focal point F from the lens, depends not only on the form of the latter, but also on the index of the refraction of the substance of which it is composed.

In a *biconvex* glass lens, whose surfaces have both an equal radius, the focal points coincide on both sides with the central points of the spherical segments, provided the index of refraction of the glass be exactly $\frac{3}{2}$.

If this index of refraction be greater, the focal point of the lens

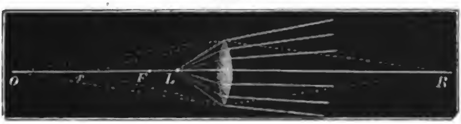
will be nearer, but if it be smaller, it will be further removed from it.

What has been said of biconvex lenses applies also to convex meniscus and plano-convex glasses; that is, they have a principal focal point in which are concentrated all the incident rays parallel with the axis; the rays coming from one of the points lying upon the axis, and removed from the glass about twice the focal distance, are united on the other side at a point likewise twice the length of the focal distance from the glass.

In a plano-convex lens whose index of refraction is $\frac{3}{2}$, the focal point is twice the radius of the curved surface from the lens.

If the luminous point *L*, Fig. 271, approach so near the lens as to lie within the focal distance, the cone of rays striking the lens is so strongly divergent that the lens is no longer able to make

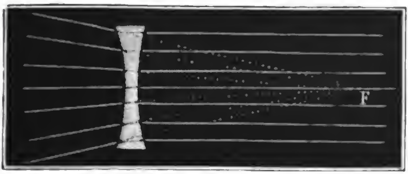
FIG. 271.



the rays converge, or even merge parallel; they diverge, however, less after than before their passage through the lens, dispersing as much as if they came from a point *O*, which is further removed from the glass than the luminous point.

Similar observations may be made respecting *concave* glasses. If the incident rays be parallel, the rays will diverge in such a manner as if they issued from the *focal point* of divergence *F*, Fig. 272; if, however, the luminous point draw nearer, and the incident rays are consequently divergent, this divergence is greater after their passage through the glass than was the case with the parallel incident rays; the nearer the luminous point is to the lens, the nearer the point of divergence, or focus, therefore approaches to the glass.

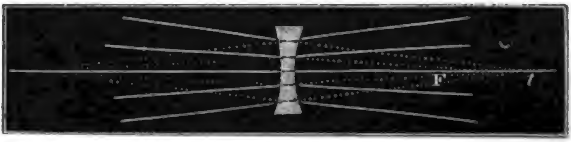
FIG. 272.



We have still to consider the case in which the incident rays are *convergent*. If the incident rays converge towards the focus *F* on the other side of the glass, the refracted rays emerging from

the lens are occasionally parallel to each other, this being the converse of what is represented in Fig. 272. If the incident rays converge more strongly, they will still converge after being refracted, but if the incident rays converge towards a point t, Fig. 273, lying at a greater distance from the glass than the chief focal point, they will still diverge as if they came from a point before the glass as seen in the figure. The consideration of this

FIG. 273.

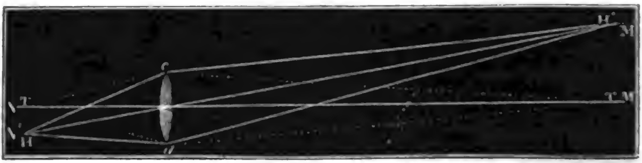


last case is important to the right understanding of Galileo's telescope, of which we purpose shortly to speak.

Secondary axes. — Hitherto we have only considered those luminous points that lie on the axis of the lens; it now remains to show that what has been said applies also to points not lying in the main axis, provided that the secondary axes make only a small angle with the main axis. By the term *secondary axis*, we designate the line we may imagine to be drawn from a point, not lying on the main axis, through the middle of the lens.

Let H, Fig. 274, be a luminous point not situated upon the main axis; then all the rays of light issuing from it will be united

FIG. 274.



in a point H', lying in the secondary axis $M\,N'$, and as far removed from the lens as the point of union T' of the rays issuing from a point T, which lies upon the main-axis and is as far removed from the lens as H.

This is easily proved. The central ray $H\,M'$ passes unbroken through the lens; further $H\,c = T\,c$ and the angle $c\,T\,M = c\,H\,M'$ (if not exactly, still very nearly so); and since the ray $T\,c$ diverges as strongly at c as $H\,c$, therefore the angle $H\,c\,H' = T\,c\,T'$; consequently the triangle $H\,c\,H' =$ to the triangle $T\,c\,T'$, and thus

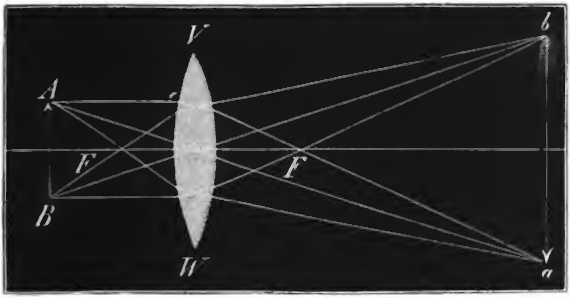
$T\,T' = H\,H'$; H' is therefore as far removed from the lens as T'.

The same result is obtained by a comparison of the triangles $T\,d\,T'$ and $H\,d\,H'$.

The field of a lens is the angle which two of the secondary axes make together; this definition will not materially affect the correctness of our proofs.

Of the images produced by lenses.—Let $A\,B$, Fig. 275, be an object on one side of the lens $V\,W$, but further removed from it

FIG. 275.



than the focal point F. The rays emitted from A are united at a point a upon the secondary axes drawn from A through the middle O of the lens; a is therefore the image of A, and b is the image of B, consequently $a\,b$ is also the image of the object $A\,B$; the image is in this case *inverted*, and is a true convergent image.

Seen from the middle of the lens, the image and object appear at the same angle, for the angle $b\,o\,a$ is equal to the angle $B\,o\,A$, being angles at the vertex; the greater size of the image or of the object depends upon which of the two is furthest removed from the glass. If we assume that the object lie twice as far as the focal distance from the glass, the image will be formed on the other side at an equal distance; in this case, therefore, the image and the object are equal in size. If the object approach nearer to the glass, the image will recede, becoming consequently larger. We therefore obtain inverted enlarged images of objects standing further from the glass than the focal distance, yet not as far as twice that distance; thus the image $a\,b$ in our figure is larger than the object $A\,B$.

If the object be further removed from the glass than twice the

focal distance, the image will be nearer; we, therefore, obtain inverted diminished images of distant objects. If, for instance, *a b*, Fig. 275, were an object lying more than twice the focal distance from the glass, we should have the diminished image *A B*.

If we term the size of the object g, that of the image g', the distance of the object from the glass b, and the distance of the image m, we have

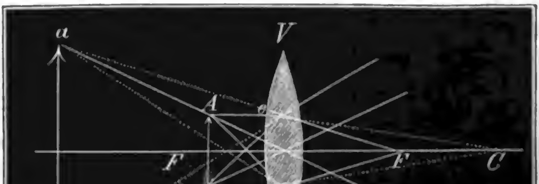
$$g : g' = b : m,$$

that is, the image and object are to one another as their distances from the lens.

In a lens of short focal distance, the images lie nearer to the glass than in one of greater focal distance; lenses give images, therefore, small in proportion to the shortness of the focal distance; and, conversely, lenses give enlarged images of small objects lying near their focal point; at an equal distance from the lens, the images will be larger in such lenses as have a small focal distance, because in that case the object approaches nearer to the lens.

If the object be within the focal distance of the lens, no convergent image of *A* can be formed, because the rays emitted from a luminous point, which lies nearer to the glass than does the focus, still diverge after their passage through it. Let *A B* in Fig. 276, be an object lying within this focal distance; then

FIG. 276.

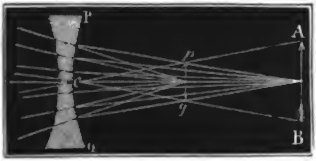


the rays passing from *A* will diverge after emerging from the glass as if they came from *a*. We may easily find the distance of the point *a* from the glass by the constructions already given. The rays coming from *B* diverge after their passage through the glass as if they came from *b*; if now there be an eye at the other side

of the glass it will receive the rays of light issuing from the object *A B* in the same manner as if they had proceeded from *a b*; *a b* is therefore the image of *A B*. As the object and image both lie within the same angle *a o b*, but the former is nearer to the glass, the image is evidently in this case larger than the object. If we use a lens as a microscope to observe small objects, the enlarged image seen, is of the kind described. We shall subsequently revert to this subject.

Concave glasses do not give convergent images, but only such as arise from convex lenses when the object lies within the focal distance. As a concave lens causes the rays emitted from a point to diverge as if they came from a point lying nearer to the glass, it is evident that concave glasses yield diminished images of objects, as we may easily see from Fig. 277, where *A B* is the object, and *p q* the image.

FIG. 277.



CHAPTER III.

DECOMPOSITION OF WHITE LIGHT.

White solar light is composed of different coloured rays.—To prove this, we need only form a solar spectrum in the manner already indicated. In Fig. 278 let *m* be a mirror, which placed before the shutter of a darkened room throws the rays of the sun into it through the opening *o*; *p* is the refracting prism, and *t* a wall on which the images are thrown. Before applying the prism, we see a white, round image at *g*, but through the prism we obtain an elongated coloured image *r u*. Fig. 279 exhibits the appearance observed upon the wall *t*.

FIG. 278.

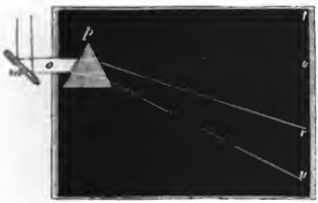


FIG. 279.

This coloured, elongated, solar image is called the *spectrum.*

The length of this spectrum increases, *cæteris paribus,* in proportion to the refracting angle of the prism. It also depends upon the substance of which the prism is formed.

By the illustration given at Fig. 278, we shall easily see that a white band is formed in the middle of the spectrum, provided its length is at least not twice as great as its breadth; if, however, the spectrum be very much elongated, the white will totally disappear, and we shall distinguish seven principal colours in it, in the following order: *red, orange, yellow, green, blue, indigo,* and *violet.*

These colours are termed *prismatic,* and *simple colours* of the rainbow. We shall soon see that there are actually a very great number of different colours in the spectrum, but that among these the eye distinguishes the seven above named.

The red end of the spectrum is always turned towards the side, at which the round, white sun-image *g,* Fig. 279, would appear, if the prism did not intervene; the red rays suffer, therefore, the least amount of deviation.

If the opening in the shutter be about 1 centimetre in diameter, when the refracting angle of the prism is 60°, and the spectrum is received at a distance of 6 metres, we shall obtain a perfect separation of the colours; that is, the spectrum will everywhere appear vividly coloured, without showing any trace of white in the centre; the separate colours appear, however, purer when the opening is smaller.

In order to see the prismatic image, it is not necessary to produce a solar spectrum by means of a prism on a white wall, it being sufficient to look through a prism towards a bright, narrow object. If, for instance, we look at the flame of a candle through a prism held vertically, it will appear considerably extended, and coloured in the manner we have mentioned. If we cut a small opening of about 1 centimetre in diameter in the shutter, we shall see the clear sky through this opening; that is, a light disc upon a dark ground. If then we look at this disc through the prism, we shall perceive instead of the white circle, a very much elongated coloured image, to which all that we have said of the spectrum cast upon the wall equally applies.

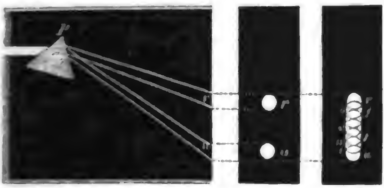
The differently coloured rays are unequally refrangible.—This

follows from white light admitting of being decomposed by the prism into rays of different colours; the red rays, after passing through the prism, form an angle with the violet, the violet rays deviating more from their original direction than the red. The violet rays are most strongly refrangible, and the red the least so. The green rays are more refrangible than the red, and less so than the violet, because in the spectrum they lie between the red and violet.

If we were to suppose for a moment that white light contained only red and violet rays, it is evident that instead of the spectrum, we should only have two solar images separated from each other, of which the one would be red, the other violet. We can, in fact, make such separate images apparent: many bodies, for instance, have the property of not admitting all coloured rays to pass equally well through them; they consequently absorb certain rays. To these belong coloured glasses and coloured fluids. If, for example, we fill the intermediate space between two parallel glass plates with a solution of sulphate of indigo, and look with a prism through this solution towards an opening in the shutter, we shall see two divided images of the opening, one red and the other blue. We obtain the same result by using a piece of dark blue glass in the place of the indigo solution.

The whole spectrum consists of a series of circularly formed images succeeding one another, and partly over-lapping each other. The smaller the opening is through which the white rays fall upon the prism, the smaller will be the separate round images, while, at the same time, the centres of the separate coloured images do not approach nearer, and consequently the different colours less overlap one another; the smaller the opening is, the purer will also the separate colours appear.

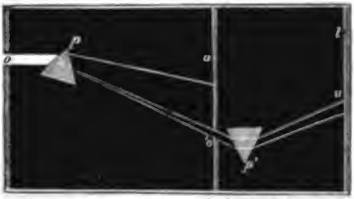
FIG. 230.



Each colour of the spectrum is simple.—Every colour is simple if it does not admit of being further decomposed into other colours: we will now show that this property is really characteristic of the prismatic colours.

If we receive a spectrum upon a wall, and make a hole somewhere about the spot on which the violet rays fall, we shall arrest all the colours, while only one coloured ray passes through the opening; this ray does not admit of being in any way further decomposed; and if it be again suffered to pass through a prism, the colour remains unchanged.

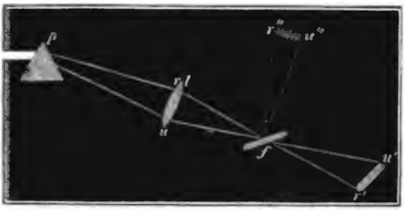
FIG. 281.



Newton applied the term *homogeneous* to simple light; a name that has been generally adopted.

White light may be recomposed from the simple colours of the spectrum.—If we receive the spectrum on a lens l, the variously coloured rays will be united by it in a point f, and if the sun's image be received upon a ground-glass, or a paper screen, it will again appear dazzlingly white, notwithstanding the differently coloured rays that fell upon the lens. If instead of holding the screen at the focal point f, we remove it further from the lens, we again obtain an inverted spectrum r' u', Fig. 282, a proof that the differently coloured rays cross each other at f, and if we apply a mirror at that point, the reflected rays will again form a spectrum u'' r''.

FIG. 282.

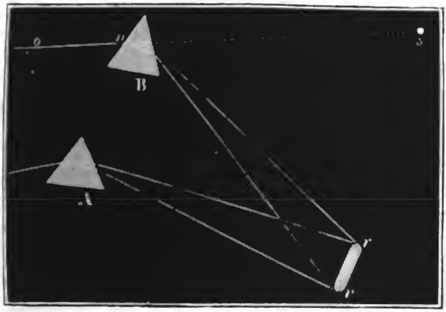


We may also use a concave mirror instead of a lens for these experiments.

That the combination of prismatic colours yields white, is proved by the extraordinary experiments made by Newton, that the long prismatic image, seen through a second prism, will under favourable circumstances again appear as a perfectly white and round disc. Let v w be a spectrum, Fig. 283, produced by the prism, and caught on a white wall. If now a second prism B be so placed that it would produce the same spectrum r v in the same place, if a ray of solar light fell upon it in the direction o n, it is clear that the rays falling from the spectrum on the

prism B will emerge in the direction $n\ o$; thus an eye at o must see a round white image of the coloured spectrum in the direction $o\ n\ s$. The position that must be given to the prism B may easily be ascertained by experiment.

FIG. 283.



If now we divide a circular disc into seven sectors, and paint them with colours that most nearly approach the prismatic hues, the disc if made to rotate rapidly will no longer appear to be coloured, but will look whitish, and it would appear wholly white, if the sections could be painted with purely prismatic colours, and if the breadth of the separate coloured sectors stood exactly in the same relation to each other as the breadths of the corresponding parts of the spectrum. *Münchow* combined the prism with clock-work, in order to be able to make experiments with pure prismatic colours on this principle, by setting the prism into rapid oscillating motion. By this motion of the prism, the spectrum moves rapidly backward and forward on a screen, and then there appears instead of the coloured spectrum a white band of light slightly coloured at the ends. The eye rapidly receives at each of the points of the screen the impressions of all the separate colours successively; these separate impressions vanish, however, and produce the sensation of white.

Of the complementary colours, and the natural colours of bodies.— As all simple colours combined in proper proportions, (that is, in the proportion given by the spectrum,) produce white light, it is sufficient to suppress one or more of the simple colours, or even simply to alter their proportion to form any shade of colour from white. If, for instance, we suppress the red of the spectrum in white light, while all the colours remain unaltered, we shall have a bluish tint, to which we need only add red, in order to restore the white. Two tints of colour fulfilling these conditions, that is, giving when combined, white, are termed *complementary* colours. Each colour has its complementary colour, for if it be not white, it is

deficient in certain rays that would aid in producing the white, and these absent rays compose the complementary colour. Violet, which passes more or less into red, is the complementary colour of different shades of green. We have already seen that a solution of sulphate of indigo in a prism yields a blue and red image of a white object. The red image is very sharply defined, the blue not so much so, passing somewhat more into violet, and less into green; the light transmitted through a solution of indigo is therefore wholly deficient in yellow and orange, and almost so with respect to all the green, and a portion of the violet. These absent colours form, however, when taken together, a mixture in which yellow predominates to a considerable extent; yellow is consequently the complementary colour to blue in the indigo solution; as yellow shades of colour are complementary to blue. The more the image approaches the green, the more will the complementary yellow merge into red.

We shall subsequently have another opportunity of speaking of complementary colours.

The prism we have made use of to decompose solar light will also serve to analyse the natural colours of bodies; and for this purpose, we need only cut off narrow strips from coloured bodies, and look at them through the prism.

We glue a row of coloured strips of paper, about 1 millimetre wide, and as seen at Fig. 284, upon a piece of black paper: let 1 be white, 2 yellow, 3 orange, 4 scarlet, 5 green, and 6 blue; the best paper for the purpose is that used by bookbinders for the titles of the back of books, as the colours are generally clear, and well defined. If now we look at these coloured strips from the distance of several feet, through a prism whose axis is parallel with the direction of the length of the strips, they will naturally appear moved out of their places; at the same time, however, all the colours will be decomposed into their elementary colours. The white paper will give a perfect spectrum with all colours, from the extreme red to the extreme violet. The coloured image given by the yellow paper approaches most nearly to the perfect spectrum. Red, orange, yellow and green are present; the lower blue and violet end alone is wanting; consequently the colour of the yellow paper requires

FIG. 284.

ly blue and violet in order to produce white. The coloured age of the piece of paper No. 3 (orange) is much less complete; e the green rays are wanting as well as the violet and blue. e coloured image of the red paper, No. 4, is the least dispersed, wing besides red only a little orange, the red of this paper is refore almost a pure prismatic red. In the colours of the er we have hitherto considered, red was contained 1 to 4; the its of these four coloured images coincide therefore above in a aight line, while below they are cut off like graduated steps. e colours of the papers 5 and 6, green and blue, contain but y little red, on which account there is scarcely any red end to coloured images they yield; and hence it follows that the two t images appear much more removed from their true position, n the image of the red paper, No. 4.

If we look through the prism at a broad, instead of a narrow ce of paper, we shall see it white in the middle, and only oured at the edges. Supposing that we look at the white p of paper *a b*, in Fig. 285, through a prism whose axis is at right angles to the direction of length of the paper, the different coloured images of the band will appear partially to overlap each other. The red image of the band extends, for instance, from *r* to *r′*, the orange from *o* to *o′*, the yellow from *g* to *g′*, &c.; the violet, finally, from *v* to *v′*; it is thus clear that the images of all the prismatic colours between *v* and *r′* coincide, the whole spot from *v* to *r′*, must therefore appear white. There is only red light between *r* and *o*; red and orange between *o* and *g*; red, orange, and yellow between *g* and *g r*; the red end of the image will, therefore, pass over to a yellowish tint. To the three mentioned colours, there succeeds next below them green, blue, &c. The upper part of the image is consequently red, passing gradually through yellow to white.

IG. 285.

The other end of the image is violet, and passes gradually ough blue into white.

What we have here said of the white strips of paper, applies ally to every white object of considerable extension seen through rism, appearing coloured only at the edges.

A broad black strip upon a white ground affords, when seen ough a prism, exactly the contrary phenomena; that is to say,

the prismatic image at the end which is least refracted appears with a violet and blue edge, and at the other with a red and yellow edge. In order to explain this inversion, we need only consider that the colours are produced not from the black strip, but the white surfaces bounding it. If the black strip be very narrow, the black in the middle will entirely disappear from the image.

Of the dispersing power of different substances.—The separation of the different rays of light which takes place in their passage through a prism is designated by the term *dispersion.* The dispersing power of a substance is great in proportion to the difference between the indices of refraction of the red and violet rays.

For water this index of refraction for the red rays is 1,330, while that for the violet rays is 1,344; the difference of the two is, therefore, 0,014. For flint-glass, the indices of refraction of the red and violet rays are 1,628, and 1,671 respectively; the difference is, therefore, 0,043, three times as great as that for water.

If, therefore, we make a water-prism, which properly placed shall refract the rays as strongly as a flint-glass prism, the breadth of the spectrum of the latter will be three times that of the spectrum of the water-prism; the dispersing power of flint-glass is consequently three times as great as that of water.

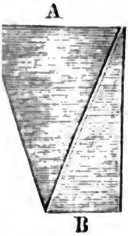
For crown-glass, the difference between the indices of refraction for the red and violet rays is only half as great as that for flint-glass, the dispersive power of flint-glass is, therefore, twice as great as that of crown-glass, although the indices of refraction for the two kinds of glass are very nearly equal.

We call prisms *achromatic* when they have the property of refracting rays of light, without at the same time decomposing them into colours, and achromatic lenses are those in which the foci of the different rays coincide exactly, showing the objects free from all coloured edges. Achromatism was long considered impossible: that is to say, it was not believed that light could be refracted without decomposition. *Newton* himself was of this opinion, because he thought that dispersion was always proportional to the refracting power of bodies. The possibility of *achromatism* was for a long period the subject of discussion between the most distinguished men of science of their day, as *Euler, Clairaut* and *d'Alembert*. *Hell* certainly made achromatic telescopes as early as the year 1733, but he did not publish his discovery. *Dollond* also made instruments of this kind in 1757, and he made them publicly known. *Dollond's* discovery was

ithout doubt an event of the highest importance to astronomy; ı order, however, to give it its full signification, it was first necesary to develop the mathematical theory of achromatism; without hich, it would be impossible to make the necessary practical nprovements. Even in the present day, when such progress has een made in optics with relation to the construction of glasses, nd notwithstanding all the assistance rendered by the calculus, chromatism must be classed amongst the most delicate problems, oth in a theoretical and practical point of view. In a work of is kind, we must of course restrict ourselves to the development the principles only on which the construction of achromatic risms and lenses depend.

If we so arrange two prisms *A* and *B*, Fig. 286, that the refracting edges are directed towards opposite sides, the action of one will more or less fully destroy that of the other. The dispersion of colour produced by *A* will be counteracted by that occasioned by the prism *B*; if, under similar circumstances, each of the prisms alone give an equally large spectrum; for in this case, the action of the prism *B*, in relation to the dispersion of colour, is exactly equal to that of the prism *A*, and *vice versâ*.

FIG. 286.



If the dispersion were actually proportional to the fracting power, as *Newton* supposed, two prisms of different ıbstances could only give equal spectra, provided the deviation oduced by the one were equal to that by the other; if, therefore, ro prisms of the kind represented at Fig. 286 were placed gether, the decomposition of colour would be stopped by this mbination, and with it the deviation likewise.

Later experiments have, however, shown, as we have mentioned, ıat *Newton* was wrong in the opinion he had formed on this subject; ıus, for instance, dispersion is much more considerable in flintass than in crown-glass, whilst the average indices of refraction both kinds of glass do not very essentially differ; with an equal eviation, the spectrum of a prism of flint-glass is almost twice as eat as that of a prism of crown-glass.

If the refracting angle of a prism be not too great, we may sume without any marked error, that the breadth of a coloured nage is proportional to the refracting angle; supposing now that e have a prism of crown-glass of 25^0, we may easily calculate e angle of a prism of flint-glass giving the same dispersion of

colour. As the total dispersion of the flint-glass is twice as great as that of the crown-glass, the refracting angle of the flint-glass must also be twice as small: that is about $12\frac{1}{2}^0$. The dispersion of colour of a flint-glass prism of $12\frac{1}{2}^0$, is as great as that of a crown-glass prism of 25^0; two such prisms, therefore, combined in the manner indicated at Fig. 286 will not produce any further dispersion of colour.

But as the indices of refraction of both kinds of glass are generally very nearly equal, the deviations of the prisms *A* and *B* will be nearly as their refracting angles; the deviation produced by *A* is nearly twice as great as that produced by *B*; the prism *B* can therefore only remove about half the deviation produced by *A*; the combination of the prisms *A* and *B* will, therefore, still produce a deviation, but not any dispersion of colour.

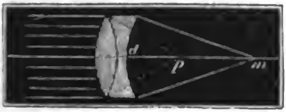
Every simple lens, whatever be the substance from which it is formed, will have a different focus for every different kind of ray, because the indices of refraction of the rays of different colours are not equal. The focus of the red rays lies further from the lens than the focus of the violet rays. The foci of the red and violet rays are not equi-distant in all lenses, as this distance depends on one hand upon the curvature of the lenses, and on the other upon the dispersive power of the substance. In proportion as the curvature of the lens from the middle towards the edge is inconsiderable, the foci for the different colours will also be nearer to each other.

The consequence of this last mentioned circumstance is that the images of such lenses appear more or less impure, and more or less bordered with coloured edges. We may be easily convinced of this by looking at the letters of a book through a lens of great curvature, or by producing the image of distant objects by such a lens on a ground-glass table, when everything will in like manner be surrounded by coloured edges. As the distinctness of images in microscopes, as well as in telescopes, was thus materially affected, the discovery of the construction of achromatic lenses was of the greatest importance in practical optics.

The achromatism of lenses depends upon the same principles as the achromatism of prisms; achromatic lenses are composed of simple lenses made of different kinds of glass. A crown-glass and a flint-glass lens are commonly combined together for this purpose. The action of lenses upon rays of different colours is such that a concave lens causes the violet rays to converge more

strongly, while a concave lens makes them diverge more powerfully than the red rays; we may, therefore, understand how a combination of a concave and a convex lens as seen at Fig. 287, is able wholly to destroy the dispersion of colour; if the two lenses be of different kinds of glass, the dispersion of colour may be stopped without, on that account, the refraction ceasing.

FIG. 287.



If a convex lens of crown-glass, and a concave lens of flint-glass produce an equally strong dispersion of colour, the two combined will produce no dispersion at all; but as flint-glass acts with a more strongly dispersive power, a concave lens of flint-glass capable of destroying the dispersion in a convex lens of crown-glass, will not be able entirely to remove the convergency of the rays caused by the convex lens; the two lenses taken together will, therefore, act as a convex lens, whilst the dispersion of colour is destroyed, thus forming an *achromatic lens*.

CHAPTER IV.

OF THE EYE AND OPTICAL INSTRUMENTS.

THE sensations of light and of colour depend upon an affection of special nerves, whose delicate extremities are distributed as a nervous membrane, named the retina. The sensation of darkness depends upon a perfect state of rest in this nervous membrane, every irritation producing the sensation of light; this irritation is most especially produced by rays of light passing from bodies in the external world through the eye to the retina, although the sensations of light and colour may be produced by other causes, and without the co-operation of rays of light coming from without, as for instance, by the pressure of the blood (scintillations before the closed eyes). An external pressure upon the closed eye, and an electrical discharge are likewise capable of producing sensations of light.

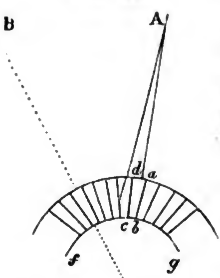
To distinguish external objects by the sight, it is not sufficient that the rays of light, passing from a body, should fall upon the

retina; but a special apparatus is also necessary for the purpose of distributing the light, by which means the rays passing from a luminous point may only strike one definite spot of the retina, and that the rays of light coming from other points may be kept from this spot; in this manner the different parts of the retina are differently affected, and a distinction of objects is consequently rendered possible. Where there is a deficiency of such an apparatus for distributing light, as is the case with many of the lower classes of animals, there is actually no sight properly so called, but simply the power of distinguishing light from darkness, day from night; yet even here a special nervous apparatus is necessary.

The apparatus intended for the isolation of the impressions of light, is not arranged in the same manner in all classes of animals, here we distinguish two essentially different kinds of eyes; 1. the *mosaic composum eyes* of insects and crustacea, and, 2. the eyes of *vertebrata* provided with *convex lenses.*

Composum eyes.—Müller was the first to throw any light by his classical investigations upon *mosaic composum* eyes. There are a very great number of transparent small cones, standing rectangularly upon the convex retina, and only those rays falling in the direction of the axis of the cone can reach its base on the retina. All laterally incident light is absorbed, because the lateral walls of the cone are invested with a darkly-coloured pigment. In Fig. 288, *f c b g* is a section of the convex retina, with the transparent cylinders upon it. It is evident that the rays passing from the luminous point *A* can only strike the retina in *c b*, the base of the truncated cone *a b c d*; the bases of the two cones contiguous to *a b c d* are no longer struck by the rays passing from *A*; a luminous point *B* sends its rays to another spot of the retina and so on. All the light coming from points, lying on the prolongation of the cone, will naturally act upon the basis of such a transparent cone, and the impressions of light from all points, sending light on the basis of the same cone, will also blend together; from which we see that the distinctness of an image on the retina is greater in proportion to the number of cones. *Müller** charac-

FIG. 288.



* Müller's Physiology, translated by Baly, Vol. II. p. 1091.

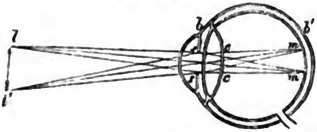
terises the sight of such eyes with striking accuracy, when he says: "an image formed by several thousand separate points, each of which corresponds to a distant field of vision in the external world, will resemble a piece of mosaic work, and a better idea cannot be conceived of the image of external objects, which will be depicted on the retina of beings endowed with such organs of vision, than by such a comparison."

The size of the field of vision of such eyes, naturally depends upon the angle made by the axes of the external cones, that is upon the convexity of the eyes. The transparent membrane covering the eye exteriorly, the *cornea,* is generally divided into *facettes,* each separate facette corresponding to the above mentioned transparent cone. The number of the facettes of such an eye is generally very great, a single eye containing often from 12 to 20,000 such facettes.

All insects have not such *mosaic composum eyes;* spiders, for instance, have simple eyes with lenses, entirely formed like the eyes of the vertebrate animals; there are also many insects which, besides the mosaic composum eyes, have also simple eyes with lenses, but the construction as well as the position of these would lead us to conjecture that they are only intended for seeing the most contiguous objects.

Simple eyes with convex lenses.—The image is formed upon the retina of eyes having collective lenses in precisely the same manner as the images of ordinary convex lenses; the rays issuing from one point of the object, and striking the anterior surface of the eye, are refracted by the transparent media of that organ towards a point of the retina. Fig. 289 represents the section of a human eye. The whole globe of the eye is surrounded by a firm, hard membrane, only transparent at the front part; this transparent portion is called the *cornea,* and the white opaque part *the tunica sclerotica;* the transparent cornea is more strongly curved than the rest of the globe. Behind the cornea lies the coloured prismatic membrane, the *iris,* which is plane, cutting off, as it were, the curvature of the transparent cornea from the remaining parts of the eye. In the middle of the iris at *s s′*, there is a circular opening, which, seen from the front, appears perfectly black, the opening bears the name of the *pupil.* Behind

FIG. 289.



the iris and pupil is the crystalline lens c c', within a transparent capsule, by which it is also attached to the outer wall of the eye. Between the lens and the cornea, there is a clear and somewhat saline fluid (*humor aqueus*), while the whole space behind the lens is filled with a transparent gelatinous substance (*humor vitreus*). The crystalline lens itself is flatter anteriorly than posteriorly.

Above the sclerotica, in the interior of the eye, is the choroid membrane (*tunica choroidea*), and over this lies the *retina,* which is an expansion of the optic nerve. The choroid membrane, which invests the whole inner cavity of the eye, is covered over with a black pigment, the object of which is to prevent the purity of the image being disturbed by reflection within the eye. For the same reason, the interior surface of telescopes is stained black.

The rays of light that fall upon the eye strike the front of the sclerotica, (the white of the eye), and are irregularly distributed in all directions, or they enter the eye through the cornea; the external rays of the pencil passing through the cornea fall upon the iris, and are irregularly distributed in all directions, by which means the colour of the iris becomes visible. The central rays pass through the pupil to the lens, and are thence refracted towards the retina in such a manner, that the rays passing from a point of an external object through the pupil, are again united in a point upon the retina. Thus an image of the object before the eye is impressed upon the retina. In Fig. 289, m is the image of the point l, and m' the image of l'.

We may prove by an experiment on the eye of an ox or a horse, that a diminished inverted image of the object before the eye is really impressed upon the retina. We must carefully open the eye in order to be enabled to see the retina through the vitreous humour, then if the eye be directed towards a window, or any bright object, we distinctly see a diminished inverted image of it upon the retina. This is most clearly seen in animals in which the choroid is destitute of pigment, as in white rabbits, whilst at the same time the back part of the sclerotica is transparent. In such eyes, the images on the retina may be seen without further preparation.

Distinct vision at different distances.—We have already seen that the image of a lens changes its position if the object be drawn nearer or removed further away; the image recedes further

om the glass in proportion as the object approaches it. As e eye acts entirely like a lens, and we are only able to see jects clearly when the points of union of the refracted rays ll exactly upon the retina, we might suppose that we could ly see objects at a definite distance, when the image was arply defined upon the retina; experience shows, however, at the contrary is the case, and that a sound eye can distinctly e all objects when removed more than eight inches from it: must, therefore, have the capacity of accommodating itself to fferent distances.

We may show this by a very simple experiment: if we make small black spot upon a transparent glass plate, and hold from 10 to 12 inches from the eye, we may see at pleasure ther the spot, or the distant objects through the glass plane. we see the remote objects distinctly, the spot will appear cloudy nd undefined, while on the other hand, distant objects will e distorted when the spot is seen with distinctness; when, erefore, distant objects appear distinct, the rays passing from e dark spot are not limited upon the retina, and conversely: e eye has thus the capacity of adapting itself to seeing at small nd great distances.

If now the rays passing from a luminous point are united efore or behind the retina, a small circle of dispersion will be rmed upon the retina instead of the bright point, and this the reason that objects at a distance, to which the eye cannot ccommodate itself, appear indistinct. This power of adaptation as its limits, for if the objects be brought too near the eye, hat organ is no longer able to make those alternations necessary or causing the image to fall upon the retina, in which case he points of union lie behind that membrane, and circles of lispersion of the separate luminous points, instead of the sharply lefined image, are formed upon it; so that it is no longer possible o distinguish the figures. A pin's-head, for instance, cannot e distinctly seen when held at 1 or 2 inches only from the ye.

As the point of union of rays from the lens is the more distant s the objects approach nearer to it, we may explain distinct ision, at different distances, by the assumption that the length f the axis of the eye may be increased or diminished at pleasure; he axis of the eye must be longer for near than for distant bjects, or in oth words, the retina is further removed from the

cornea for near objects. *Olbers* has calculated the prolongation of the axis of the eye necessary to explain distinct vision at a distance extending from 4 inches to infinity. The numbers given in the following little table are taken from these calculations.

DISTANCE OF THE OBJECT.	DISTANCE OF THE IMAGE FROM THE CORNEA.
Infinite.	0,8997 inches.
27 inches.	0,9189 „
8 „	0,9671 „
4 „	1,0426 „

According to this calculation, a prolongation of the axis of the eye of about 1 inch would suffice, without any change of curvature of the lens and the cornea, to explain distinct vision from 4 inches to infinity.

If we would explain the power of adaptation of the eye by a change of the curvature of the cornea, we must according to *Olbers'* calculations assume the following variations:

DISTANCE OF THE OBJECT.	RADIUS OF THE CORNEA.
Infinite.	0,333 inches.
27 inches.	0,321 „
20 „	0,303 „
5 „	0,273 „

If thus the radius of curvature of the cornea were only altered from 0,333 to 0,300, and the axis of the eye could be lengthened or shortened about half a line, the power of adaptation possessed by the eye for all distances from 4 inches to infinity, would admit of explanation.

However such an assumption may explain the power of adaptation possessed by the eye, its correctness is by no means proved; in fact, many objections have been raised against it, and at any rate so great a change in the curvature of the cornea is somewhat improbable.

Other physiologists endeavour to explain this power of adaptation of the eye by the compression and change of position of the lens, and although this may be probable, it is by no means proved with certainty. This capacity may, perhaps, be derived from a co-operation of all these causes.

Distance of distinct vision. Short-sightedness and long-sightedss.—It has already been observed that objects when brought) near the eye, can no longer be distinctly seen. There is certain distance for every eye, beyond which an object must t be placed if it is to be distinctly seen without exertion; this distance of distinct vision we involuntarily hold a book reading, if it be printed with type of ordinary size. If we ing the object nearer, it cannot be seen without effort, while a still closer proximity, distinct vision is no longer possible. a perfectly sound eye, the distance of distinct vision is about or 10 inches: where this distance is less, we term the eye *rt-sighted*; where it is greater, *long-sighted.*

Indistinctness of vision with reference to objects in close ximity, arises, as we have already observed, from the rays ssing from the point of a near object diverging so strongly that refracting media of the eye are no longer able to make them fficiently convergent to produce a re-union upon the retina; the point of union falls in this case behind the retina, they pear with a circle of dispersion. If we are able to hinder e formation of this circle of dispersion, we may see objects when ought very near to the eye.

If we look through a hole made with a pin in a card, holding e eye close to it, we shall still distinctly see the letters of a book, ich will appear considerably enlarged, whilst on the removal the card, we shall no longer be able to distinguish the letters. e reason of this is, that rays can only reach the eye from e point of the neighbouring object, passing in one direction ly, through the fine opening in the card, and these will also rike the retina in one point only, whilst if the card do not ep off the other rays, a whole pencil will pass from one point the object through the pupil into the eye, forming a circle dispersion upon the retina.

We may here mention the interesting and instructive experiment Father Scheiner.* If we make, in a card, two minute orifices ith a needle, at a smaller distance from each other than the ameter of the pupil, and hold these openings close to the eye, e see a double image of a small object, as a pin's-head, held ithin the visual distance. From this small object there pass two ry minute pencils of rays through the apertures into the eye. hese rays converge towards a point lying behind the retina,

* Ocules sine Fundamentum Opticum, etc. 1652.

falling upon the latter at two different points; these are two isolated points of the circle of dispersion, which would arise upon the retina if the other rays were not intercepted by the card.

If now we remove the small object more and more, the images will approach, because the rays falling upon the eye through the apertures will diverge less, and consequently be refracted towards a point lying nearer to the retina. If the object be removed from the eye to the distance of distinct vision, the two images will perfectly coincide, since all rays passing from one point lying exactly at the distance of distinct vision, will be concentrated at one point of the retina.

We naturally see near and distant objects with equal distinctness through a fine aperture in a card held close before the eye, without there being any necessity for the eye to accommodate itself to the distances, since the rays passing from one point of the object only strike the retina at one point; through such an aperture, we may therefore at the same time, distinctly see near and distant objects; we may here ask what are the conditions of adaptation necessary for an eye in looking through a fine aperture? And the answer naturally is, that in its normal condition, for the maintenance of which no effort is necessary, the eye is in the state requisite for seeing objects which lie at the distance of distinct vision.

Let us now revert to *Scheiner's* experiment: if a distant object be observed through both openings, the rays passing into the eye through these two apertures must evidently meet at one point before the retina, as the condition of each adaptation does not change in the eye; but the two pencils diverge again behind the point of intersection, striking the retina at two different points, when consequently distant objects will be seen double. *Through the two small apertures, therefore, we only see a small object single, when it lies at the distance of distinct vision.*

On the principles deduced from Scheiner's experiments, instruments have been constructed which bear the name of *optometers*, and serve to define the distance of distinct vision.

Short-sightedness, Myopia, and *long-sightedness, Presbyopia,* are defects, the causes of which must be sought for in a deficiency of the power of adaptation, on which habit exercises a very injurious effect; short-sightedness often arises from the neglect of exercising the sight on distant objects, and children who bend the head too closely over the paper in writing or reading, frequently become

rt-sighted in consequence. A prolonged use of the microscope l cause an otherwise sound eye to become temporarily short-ıted, this condition frequently continuing for some hours.*

[he simplest method of improving either defect consists, as we e already stated, in holding a card having a fine aperture close the eye. By this means, the principle of which has already n explained, the distinctness of the image will certainly be tored at the expense of the clearness.

Another method is the use of spectacles, which are constructed h concave glasses for short-sighted eyes, and with convex sses for long-sighted eyes. In a short-sighted eye, the images distant objects fall before the retina, and the eye has not the ver of accommodating itself in such a manner that the images ı be formed upon the retina; we, therefore, on this account alter : refractive power of the eye by the use of concave glasses, by ans of which the rays coming to the eye converge less strongly, l thus enable the rays to unite upon the retina.

In far-sighted persons the image of contiguous objects falls hind the retina, without the eye being able to accommodate elf to this condition of refraction; we therefore use convex ısses to make the rays more convergent, and thus bring the int of union upon the retina.

More or less strong glasses must be employed where there is ›re or less short-sightedness present; and the object to be :ended to in the choice of the glasses, is that, in co-operation th them, the distance of distinct vision may be rendered the me as in a perfectly sound eye, that is about 8 or 10 inches.

Short-sightedness appears more frequently in middle age, and ıg-sightedness in old age.

Achromatism of the eye.—In ordinary lenses, the foci of the ys of different colour do not coincide, and hence arise those loured edges which we perceive on the outlines of objects seen rough a common lens; that is, if the opening of the lens is rge, and the objects are not in the middle of the field of view. e have already seen how lenses may be made achromatic, or free ›m this defect. The human eye is likewise an achromatic instru-ent, for we see the objects pure and without coloured borders.

As the achromatism of lenses may be effected by a combination different refracting substances, and of unequal dispersive power, ıe possibility of the achromatism of the eye may easily be con-

* Müller's Physiology.

ceived, since a ray of light in its course through that organ has to traverse successively three different media, which, when taken together act as an achromatic lens.

The eye is not, however, perfectly achromatic, for we only see an object pure if the eye can properly accommodate itself to the distance of this object. We see, for instance, very vividly coloured edges on a dark object lying before the eye if we look beyond it upon distant objects and see these distinctly; if, for instance, we make a hole of about 1 line in diameter, and holding it 5 or 6 inches from the eye, look through it towards some distant object, the edges of the opening will appear coloured.

Relation between the perception of the eye and the external world. —The act of vision depends essentially upon the affections of the retina being reduced to a state of consciousness by certain means unaccountable to us. We actually only take cognizance of one definite condition, one certain affection of the retina; but that we convert the images of the retina at once into representations of the external world is an act of immediate and spontaneous judgment, and we have attained such certainty in this by constant self-corroborating experience, that we do not feel the retina to be a perceptive organ, and confuse the direct impressions with what, according to our judgment, is the cause of them. This substitution of the judgment for sensation occurs involuntarily, and so to say, has become a second nature to us.

As we put for the sensation upon the retina a representation of the external world; we, in like manner, substitute an object external to us for every image on the retina. That we seek in a definite direction the object corresponding to a definite image of the retina, is as much the result of continuous consequent experience as the action of our sense of sight with reference to the external world.

If we suppose the object and its image on the retina connected by a straight line, this is the direction in which we perceive the images externally. *Volkmann* has shown that if we draw a straight line from each point of the image on the retina towards the corresponding points in the external world, all lines will intersect each other at one point, lying in the interior of the eye and behind the lens; this point he calls the point of intersection.

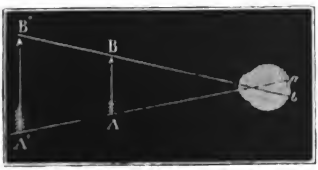
It has been already shown that diminished and inverted images are formed upon the retina, and hence the question arises, why we do not see all things *inverted?* This question is satisfactorily

answered in the above considerations. The knowledge of the existence of an image on the retina, and of its lying on the upper and lower parts of the retina, on its right or left side, can only be attained by optical investigations; the sensation of the retina does not occur as consciousness, but is involuntarily projected externally in a certain direction, namely, that in which the objects lie that cause the images on the retina. In this direction, however, we also find objects by other perceptions of sense: as, for example, by the sense of feeling; there is consequently the greatest harmony between the different perceptions of sense in relation to locality; and without such a state of harmonious accord, we should see objects inverted.

With the representation of external things, by means of the organ of vision, we combine also a representation of their size and distance. The images on the retina lie side by side, and if we do not recognise the corresponding objects to be immediately contiguous to each other, but situated the one behind the other, that is, if we raise ourselves from the plane on which our observations are made to an imaginary representation of the depth of space, this is an act of the understanding, and not of sensation. The young child has no conception of distance, and grasps at the moon as at objects immediately within his reach. The conception of the depth of visual space is only acquired by moving in space, by observing that images change by this motion, and enabling us by our own change of place to form an idea of the distance of objects.

The apparent size of objects depends upon the size of the image on the retina. If we suppose lines drawn from both extremities of the image on the retina towards the corresponding extreme points of the object, these lines will intersect each other at an angle x, which we call the angle of vision; the size of this angle is, however, proportional to the size of the image on the retina, and we may therefore say that the apparent size of objects depends upon the size of the visual angle under which they appear. Two objects of different size, as $A\ B$ and $A'\ B'$, may have the same apparent size, if their size be proportional to their distance from the eye; different objects, therefore, whose sizes are as 1 : 2 : 3 &c., will appear at once, twice, thrice the distance under an equally great angle of vision.

FIG. 290.



Our judgment, regarding the actual size of objects and their distance, is only acquired by continued experience, and may by practice attain a most extraordinary degree of certainty.

Vision with both eyes.—When we direct both eyes to one object, we see only a single image, provided the eye accommodate itself to the distance at which the object is placed; we always see a *double* image if the eye accommodates itself to a greater or smaller distance; we see it sharply and distinctly when we see it singly; and it appears indistinct and distorted when seen doubly.

We may, at will, see a single or double image, by holding before the face one or two fingers exactly behind the other, at a distance of about 1 and 2 feet, when the back one will appear double if we direct the axes of the eyes to the foremost one, and *vice-versâ.*

In Fig. 291, *L* and *R* are the two eyes, *A* and *B* two objects

FIG. 291.

FIG. 292.

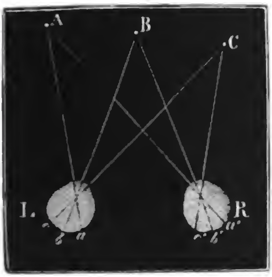
lying at different distances. If we look at the object *A*, the axes of both eyes (the axis of the eye is the straight line connecting the middle of the retina with the central point of the lens and the pupil) will be directed towards *A*, and will consequently make a tolerably large angle with each other; the image of *A* appears in each eye upon the middle of the retina; if now we look at the distant object *B*, as represented in Fig. 292, the angle of the axes of the eyes will be smaller, and the image of *B* will appear in each eye in the middle of the retina.

If we look at *A*, as represented in Fig. 291, the image of *B*

will lie to the right of the middle of the retina in the left eye, and to the left of it in the right eye; the images *b* and *b′*, do not, therefore, lie in corresponding parts in both eyes; and this is probably the reason of the object *B* being seen double. As the image *b* lies to the right of *a* in the left eye, *B* will appear to be to the left of *A*, whilst the right eye sees the object *B* to the right of *A*, the image *b′* being left of *a′*. If we have fixed both eyes on the object *A* in such a manner that we only see it single, whilst *B* appears double, we may make the left or right image of *B* disappear, according as we receive the rays passing from *B* upon the left or right eye. If, on the contrary, we see the distant object *B* in such a manner that *A* appears double, as in Fig. 292, the image of *A* on the right will disappear, if we cover the left eye.

It is not necessary that both axes of the eye should be exactly fixed upon an object to enable us to see a single image with both eyes, that is, the image need not fall in the middle of the retina in each eye, since in that case we could only see one object single, while all others would appear double. A whole series of objects may at the same time be seen single with both eyes, if they only cast their image on corresponding parts of the retina in both eyes. In Fig. 293, *L* and *R* represent the two eyes, *A B* and *C* three different objects lying before them; the images of the three objects follow the same order in both eyes, that is to say, the image of *B* lies in the middle, the image of *C* to the left, and that of *A* to the right, upon the retina of both eyes; as the images *c* and *c′* on the retina, lie to the left of *b* and *b*, both eyes see the object *C* to the right of *B*; in the same manner, both eyes see the object *A* to the left of *B*, as the images *a* and *a′* on the retina are to the right of *b* and *b′*.

FIG. 293.



If an object appears single to both eyes, that is, if its image falls upon corresponding parts of the retina in both eyes, we see it more clearly than with one eye, and of this we may easily convince ourselves by looking at a strip of white paper, and then hold up a black screen in such a manner as to conceal half the paper from one eye, the portion of paper seen simultaneously by

both eyes, appears higher than the other half which is only seen by one eye.

The reason of our being able to see singly with both eyes, is probably to be sought in the course of the various fibres, and not as the consequence of habit. Müller, in whose writings much may be found regarding the different experiments that have been made to elucidate this wonderful chain of causes, says, "The eyes may be compared to two branches with a single root, of which every minute portion bifurcates so as to send a twig to each eye."

Limits of visibility.—In order that an object continue visible, it is necessary that the angle of vision under which it appears should be within certain limits, depending very much upon the light transmitted by the object and its colour, the nature of the back-ground, and the individual characteristics of the eye. To an eye of ordinary power, an object is still visible with a moderate degree of light at an angle of 30 seconds, and a light object, as a silver wire, may be seen on a dark back-ground under an angle of vision of 2 seconds. Dark bodies may also be very distinctly seen on a white ground, even when they are very minute; thus an eye of moderate power may see a hair when held against a tolerably clear sky at a distance of 4 or 6 feet.

Duration of the impression of light.—If we describe a circle rapidly with a burning coal, we are unable to distinguish the coal itself, seeing only a fiery circle. The cause of this phenomenon arises from the part of the retina, affected by an impression of light, not recovering its tranquillity instantaneously after the impression itself has ceased; from the same reason we are unable to distinguish the spokes of a rapidly revolving wheel, and the upper surface of a top painted with alternate sectors of black and white, as seen in Fig. 294, will appear gray. But if the top, after rotation in the dark be lighted by a flash of lightning, or an electric spark, we are able clearly to distinguish the separate sectors.

FIG. 294.

If we make two holes diametrically opposite to each other in a pasteboard disc of 2 or 3 inches in diameter, and draw strings through them as seen in Figs. 295 and 296, we may by means of the threads cause the disc to revolve so rapidly as to show alternately first the one side and then the other. If we then make

on one side a black stripe in the direction of the two little holes, and on the other side one at right angles with them, we shall see a

FIG. 295.

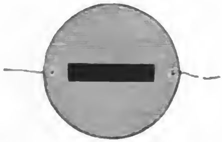
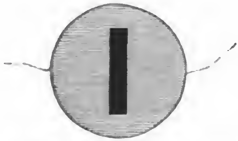


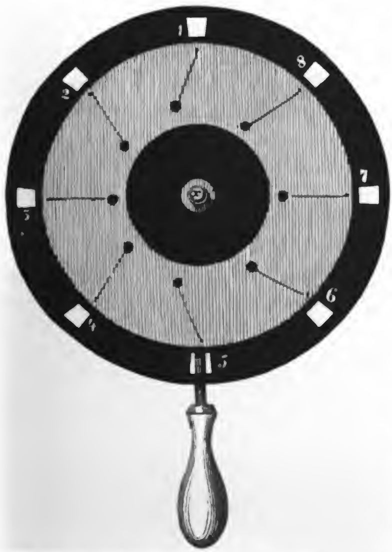
FIG. 296.



cross on making the figure revolve rapidly, because the impression produced upon the eye by the horizontal stripe is not obliterated when the vertical stripe becomes visible. If we paint a cage on one side, and a bird on the other, the bird will appear to be within the cage on making the figure revolve rapidly.

A very ingenious and pretty apparatus has been constructed, on the principle of the duration of the impression of light, and is called the *phenakistiscope*, or the *magic disc*. A disc of 20 to 25 centimetres in diameter, may be put into a rapid rotatory motion about a horizontal axis x; at the edge of which there is a succession of apertures at equal distances from each other. In the *magic disc* represented in Fig. 297, there are 8 such apertures. To the circle formed within these 8 apertures, a smaller and painted disc is fastened, on which the same object is represented in 8 different positions, each aperture corresponding to a different position. In our figure a very simple object, merely a pendulum, has been delineated. Under the opening 1, the pendulum is represented as

FIG. 297.



having attained its extreme position to the left; under 2, we see it nearer to its position of equilibrium; at 3, it has reached this point, &c. This apparatus must now be held before a looking-glass, in such a manner that its painted side may be turned towards the glass, on which we are to see the reflection of the coloured disc through one of the openings, the upper one for instance. As the disc revolves, one opening after the other passes before the eye, but as the intervening spaces pass before us nothing will be seen. If we assume that at a definite moment, the opening 1 passes before the eye, we shall see below it the pendulum in its greatest deviation; the impression of light received by the eye at this moment will remain until the second opening has come before the eye, and now the pendulum will appear in the same place as when seen in its greatest stage of deviation, but somewhat nearer to a position of equilibrium; the image of this second position will remain in the eye until that of the third position has come to the same point, and then we shall see the pendulum in a state of equilibrium; the representations of the pendulum passing thus successively before the eye, cause the deceptive impression that we actually see the pendulum oscillate. Instead of a pendulum, we may choose some other object, and represent it in as many different positions as there are apertures, so that each one of the latter may correspond to a different position of the object. The movements of men or animals may in this manner be most successfully given by merely representing them in different and successive phases.

As objects must have a certain magnitude in order to be perceptible to the eye, so must also the impression of light endure for an appreciable time in order to produce an impression upon the retina. For this reason we do not see a very rapid body, as a cannon-ball; the image of the flying ball passing over the retina with such rapidity as to prevent its being perceived by any part of it.

The after-effects produced upon the retina will be stronger, and last longer the more intense and lasting the primitive effect is. The after-images of light objects will be light, and those of dark objects dark, if the eye be withdrawn from all subsequent action of light. If, for instance, we look for a length of time continuously through a window towards the clear sky, and turning suddenly away, close the eye, we shall still see the light intervening spaces bounded by the dark window-frames; if, on the contrary,

: turn the eye towards a white wall, the after-image which s originally dark will appear light, and inversely; thus we shall : the window-frames light, and the intervening spaces dark. is inversion is easily explained: if the eye, already dazzled, be ·ned towards the white wall, the parts of the retina previously ected by the bright light will be less sensitive to the white ht of the white wall than those parts on which the image of the ·k window frames has fallen.

Coloured secondary images.—Our organs of vision often expe- nce impressions of light not immediately produced by external ects, but arising from a peculiarly irritable condition of the ina. Such colours are termed *subjective*, and also *physiological.* these belong coloured secondary images, and the colours pro- ced by contrast.

The secondary images, of which we have spoken in a previous ture, are always more or less coloured, and this coloration is per in proportion to the intensity of the primitive impression light occasioning the secondary image. If, for instance, we k for some time fixedly at a wax taper, and, closing the eye, turn ards a dark part of the room, we shall still seem to have the flame ore our eyes, although it changes its colour by degrees; at first ecomes quite yellow, passing then from orange to red, next m red through violet into a greenish blue, which becomes ker until the secondary image entirely disappears. If, on contrary, we turn the eye that has been dazzled by the ne towards a white wall, the colours of the secondary image will ceed each other in an almost inverse order, that is, we shall first see a dark image upon a light ground, becoming blue, en, and yellow, and finally blending with the white ground, so o be no longer distinguishable from it when the secondary image quite disappeared, that is, when the retina has recovered lf. The transition from one colour to another begins at the rgin, and distributes itself gradually towards the middle. We y observe similar phenomena in the dazzling images of white er lying upon a black ground, and lighted up by the , &c.

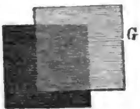
f while the coloured secondary image still remains in the closed , the eye is opened, and directed towards a white wall, we shall upon the latter an image complementary to the one seen the same time on closing the eye. If the secondary image

were red to the closed eye, on opening the eye, and directing it to a white surface, we should see a green image.

If we look fixedly for some time at a coloured spot on a white ground, we shall see a secondary image in the complementary colours; if the spot were blue, the secondary image would be yellow; if it were red, the secondary image would be green, &c. This phenomenon is caused by the retina becoming more indifferent to the colour of the object, and consequently more sensitive for those colours contained in white light which are not in the tints of the object producing the dazzling effect.

The reason of the retina becoming gradually indifferent to a colour by looking at a strongly lighted object of the same hue is, that the colour grows by degrees more and more faint and unapparent. We can most easily convince ourselves of this in the following manner. If after looking fixedly for a long time at a red square resting upon a white ground, we turn the eye somewhat aside, so that the complementary secondary image may still fall partially upon the coloured square, as represented in Fig. 298, we shall see the free portion of the secondary image green, whilst the portion of the original image which has become free (that is, the part sending its rays to those places on the retina which had not previously been impressed by the red light,) will appear to be of a bright red; where the two squares touch each other, however, we shall see a far fainter red, for the rays passing from this portion of the objective red square impinge upon the same parts of the retina which have already become less sensitive to the impression of red light.

FIG. 298.



Colours of contrast.—A gray spot appears darker on a white surface, and lighter on a black one, than if the whole surface were covered with the same gray tint. The following experiment shows this very clearly. If we bring a narrow opaque body, such as a pencil, for instance, between the flame of a taper and a white surface, we shall see a dark shadow upon a light ground; if then we place a second flame near the first, we shall see two dark shadows upon the light ground; but yet each one of these shadows is as strongly illumined by the flame as the whole surface was before, although we considered the surface previously to be light, while the shadow appears now to be dark: this experiment shows the important effect produced by contrast.

The phenomena of contrast are still more striking in considering

coloured objects, in which we often see complementary tints which were not objectively before present.

When we lay a narrow gray strip of paper upon light green paper, it will appear reddish; while if we lay it upon blue paper, it will appear to be yellow; in short, it will always be complementary to the colour of the ground. This experiment is very clearly seen if we glue a strip of white paper of about 1 millimetre in width to a plate of coloured glass, and then look through it towards some white surface, as a sheet of white paper, or also, if we entirely cover one side of the glass with thin paper, and fastening the narrow strips to the other side, hold the glass before the flame of a taper; the strip will then appear complementary to the colour of the glass, consequently red upon a green glass, and blue upon a yellow glass, &c.

We must here include the *coloured shadows* which appear when a narrow body throws a shadow, or coloured light, and when this shadow is illuminated by white light. Such shadows as these are most easily obtained in the following manner: if we let rays of light fall through a coloured glass upon a white surface, for instance, a piece of white paper, so that it may appear coloured, and if we receive upon any spot, by means of a narrow body, the coloured rays lighting the paper, we shall obtain a narrow shadow, only lighted up by the white daylight distributed around; the shadow will appear complementary to the colour of the ground; if a red glass be used, the shadow will be green; if a yellow one be used, the shadow will appear blue, &c. The colours of these shadows are purely subjective.

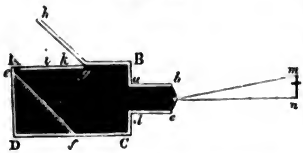
We often observe coloured shadows which are really objectively variegated; they arise where a body casts two shadows by double illumination, and where the sources of light are of various colours, as in that case each shadow is illuminated by light of different colours. Such coloured shadows arise when the bluish light of the sky falls at twilight into a room where a candle is burning; thus, if we hold a rod in such a manner that it shall cast one shadow in the candlelight, and another in the daylight, upon a white surface, we shall obtain one blue and one yellow shadow; the one being illuminated only by the bluish daylight, and the other by the yellowish flame; in this case also, contrast may exercise a great influence upon the intensity of the phenomenon of coloration, and, consequently, a partially objective and a partially subjective origin may be ascribed to the appearance.

The phenomena of coloured nebulous images may be explained by the circumstance that when a portion of the retina is affected by coloured light, this direct effect re-acts upon the neighbouring parts of the retina in such a manner, that they are converted into some of the colours complementary to the primitive impression.

This combination of mutually complementary colours produces an agreeable impression upon the eye, as may be easily understood, if we consider that when any portion of the retina is affected by any one colour, it will manifest an effort to call forth the contrasting colour on the neighbouring parts. Every combination of colours, not complementary to each other, is on the contrary inharmonious, producing an impression which will be more disagreeable the more intense the colours are; combinations of this kind are said to be glaring and repulsive: thus, for instance, while a green uniform faced with crimson will produce an agreeable impression, a red uniform faced with yellow will be universally condemned as deficient in good taste.

The Camera Obscura.—This apparatus invented by the Neapolitan, *Porta,* in the middle of the seventeenth century, consists essentially of a convergent lens of somewhat considerable focal length, by which the image of remote objects, as of a landscape, is depicted; in order to heighten the effect as much as possible, it is necessary to exclude carefully from the plane on which the images are thrown all lateral light; the image must, therefore, be received in a *dark chamber.*

FIG. 299.

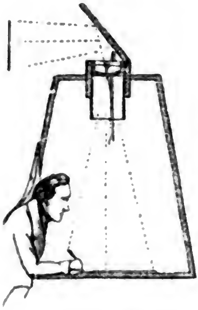


The forms most commonly given to the Camera Obscura, are represented in Figs. 299 and 300. Fig. 299 is a box having a projection *a b c d,* in which a convergent lens *b c* is inserted; the rays entering the dark box through this lens are reflected upwards by a glass plane inclined at an angle 45° towards the axis of the lens, and so arranged that the image of a distant object at *i k* can be received upon a ground glass plate. The cover *g h* serves to exclude as much as possible all extraneous light from the image. If the ground side of the glass be turned upwards, we may trace upon it with a pencil the outline of the image arising at *i k,* and thus obtain a drawing of the objects true to nature.

Fig. 300 represents a somewhat hollow box, at the bottom of

ıich a sheet of white paper is laid; through the upper surface the box there passes a tube containing the convergent lens,

FIG. 300.



over which there is a plane mirror inclined at an angle of 45° towards the vertical. The rays coming from the object are reflected downward from the mirror, so that the image is formed on the surface of the paper. This image is very bright, owing to all the lateral light having been excluded by the walls of the box, by which means we are easily enabled to trace the outlines of this image with a pencil.

The beauty of the images depicted in a *Camera Obscura* has excited the desire, if possible, of permanently fixing them, and though most persons have regarded this object as impracticable, ere are still some who have made the attempt. Since light oduces chemical actions, as, for instance, blackens chloride of lver, there appears at any rate to be a possibility of procuring ːrmanent impressions of the images formed in the *Camera Obscura.* 'e will presently proceed to discuss the discovery of *Daguerre,* hich was essentially that of perpetuating in a most wonderful anner the images of the *Camera Obscura.*

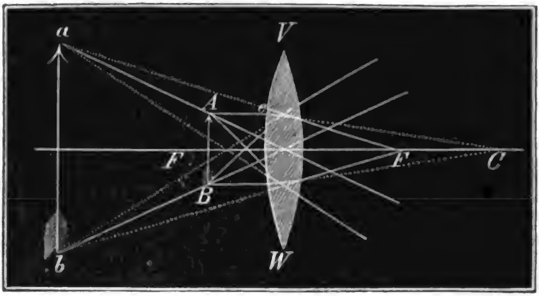
The most advantageous construction of the *Camera Obscura* ɪr the Daguerrotype pictures, is that given to it by *Voigt-inder,* of Vienna, to this apparatus. The lens used by him is a ɔmbination of crown-flint glass lenses, in which the images are ıuch more sharply defined than in the common achromatic ːns.

The magnifying lens or simple microscope.—We have already seen ıat the apparent magnitude of an object depends upon that of the ngle of vision under which it is seen; the angle of vision increases ı amount in proportion as the object is brought nearer to the eye; ut we only bring it within certain limits, that is, within the distance f distinct vision from the unaided eye, when we would distinguish he outlines and the separate parts; and consequently the magnitude f the angle of vision is circumscribed. Every instrument admitting f a further enlargement of the angle of vision for small conti-ıuous objects than the naked eye allows of, is called a microscope. ccording to this explanation, the opening in the card described bove, is a microscope, that is a *simple microscope,* although by

this term, we generally only designate convex lenses of small focal length.

In order to understand how a simple convex lens can serve as a microscope, we must look at Fig. 301. If *V W* be a convex

FIG. 301.



lens, and *A B* an object lying within the focal length of the glass, then all the rays, passing from a point of the object *A B*, will diverge after their passage through the lens, exactly as if they came from the corresponding point of the image *a b* as we have already shown; an eye behind the lens will be able to see the object distinctly through the lens, if the image *a b* be at the distance of distinct vision; in this case, however, the object being much nearer to the eye, we should consequently be unable to see it without the lens. The magnifying power of the lens depends, therefore, essentially upon the means it gives us of bringing the object very near to the eye, and thus naturally increasing the angle of vision. To determine the magnifying power produced by the lens, we must compare the magnitude of the angle of vision, under which the image *a b* appears to the eye when lying at the distance of distinct vision, with that of the angle of vision under which the object itself would appear if it were just so far removed from the eye.

The angle under which *a b* appears, can only be ascertained if the distance of the glass from the point of intersection in the eye be known; but as we hold the eye close to the glass, the thickness of which is inconsiderable, we may, without any marked error, assume that the point of intersection coincides with the central point *o* of the lens; and under this supposition the magnifying power is easily calculated.

Seen from O, the object $A\ B$ and the image $a\ b$ appear under an ıal angle of vision, we therefore find how much it is magnified we compare the angle of vision under which $A\ B$ appears with ıt under which the same object would appear if removed from O the distance of distinct vision, that is, to the position of the image ı. As the apparent size of an object is inversely proportionate its distance from the eye, so is the angle of vision $A\ O\ B$ to angle under which $A\ B$ would appear if seen from O, if this ject were removed to $a\ b$, or inversely, as the distance of the ject $A\ B$, and of the image $a\ b$ from O. If we designate as d, distance of the image from O, and the distance of the object B from the eye as x, the magnifying power will be $\frac{d}{x}$, d being distance of distinct vision.

If we were to assume what certainly is not the case, that the age is within the distance of distinct vision, and the object in focus of the lens, the magnifying power would be $\frac{d}{f}$, f represent the focal length of the glass. This expression $\frac{d}{f}$ es not certainly give us the true value, but it enables us to proximate to a correct estimate of the magnifying power of the ıs.

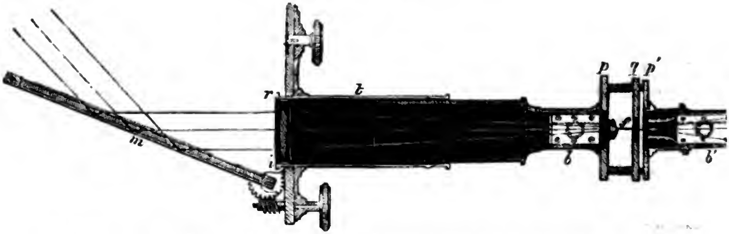
If the image $a\ b$ were at the distance d, the object would be hin the focal distance; x is therefore in every case smaller than the true value of the magnifying power is, therefore, at all events newhat greater than $\frac{d}{f}$.

If, for instance, the distance of distinct vision be 10 inches, and focal length of the lens 2 inches, the magnifying power will l be somewhat more than $\frac{10}{2}$, that is, rather more than 5.

The smaller the value of f, the less will be the focal distance of the s; the less also will be the value of x in proportion to the great-s of the value of $\frac{d}{x}$, and, consequently, the greater will be the gnifying power. A lens of small focal distance magnifies more ongly than one of greater focal distance.

The Solar Microscope.—This instrument, the action of which ongs to the most interesting and instructive in optics, consists a system of glasses serving to illuminate objects, and of a

FIG. 302.



system of lenses of short focal distances giving a convergent image of the objects.

The mirror *m*, Fig. 302, reflects the solar light along the tube *t*, parallel with its axis. The lens *i r* makes the rays somewhat convergent, a second lens *f* increases this convergence still more, so that the rays are united at a focus, which is very near to the object under examination. In order that this may always be rendered possible, the lens must be made moveable; this motion is imparted by a screw, the knob of which is outside the tube and let into a little notched rod fastened to the setting of the lens.

The objects secured between or upon glass plates, are brought between the metal plates *p'* and *q*. As the plate *q* is pressed by springs against *p'*, the objects are held by this pressure, and thus prevented from slipping.

If the object be properly adjusted and illumined, it is easy to obtain an enlarged image of it. For this purpose we make use of the achromatic lens *l*, which is really the object-lens. A notched rod is fastened to the setting of this lens, in which a slide is inserted, by which the lens *l* may be moved at will. We now adjust the lens at the proper distance from the object, until we have obtained a sharp, clear image upon a white wall, a piece of linen, or a paper screen, at a distance of 10, 15 or 20 feet. As an actual image is formed here, it necessarily follows that the object must be at the other side of the focus of the lens *l*. We may calculate the magnifying power, by dividing the distance of the object from the lens by the distance of the image from it. If, however, we want to observe directly the amount of the magnifying power, we must make use of a glass micrometer, the magnitude of whose divisions is known, and then measure the size of the divisions in the image.

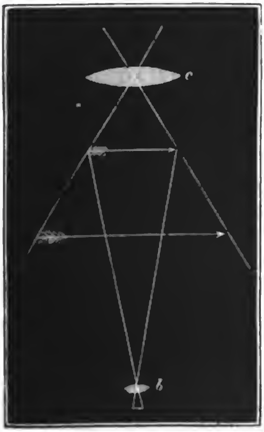
Similar microscopes have also been constructed in which the light of the sun is replaced by artificial light, as, for instance, by the light of a ball of lime (Drummond's light) ignited by the oxy-hydrogen blow-pipe, or by the light of a lamp of great illuminating power. The magnifying power will be small in proportion to the smallness of the illuminating power of the lamp.

The Magic Lantern (laterna magica) depends upon similar principles, the only difference being that the objects are painted in large dimensions upon glass, and are lighted by a lamp allowing at most of 15 to 20-fold magnifying power.

The Compound Microscope.—The principles on which the construction of all microscopes depend, however different in their arrangements, are the following:

1. The objects to be subjected to experiment, are placed near a convex lens *b*, of short focal distance, and somewhat beyond the focus. This lens is called the *object glass*, whether it be simple or compound, achromatic or not achromatic.

FIG. 303.



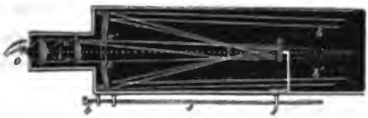
2. The actual and magnified images, thrown by the objects through the object-glass, are seen through a convex lens *c*, which serves here as a microscope; this second lens is called the *ocular* or *eye-glass* of the microscope, whether it be simple or compound, achromatic or not achromatic.

Thus every dioptric microscope is essentially composed of an object-glass, and an eye-glass; and the magnifying power of the microscope is the product of the magnifying powers produced by these glasses. If, for instance, the object-glass magnified 5 times, and the eye-glass 10 times, such a microscope would consequently magnify the diameter of objects 50 times, and these surfaces 2500. We should obtain a linear power of 1000, and a superficial power of 1,000,000 if the magnifying powers of the object-glass and the eye-glass were respectively 100 and 10, or 50 and 20, or 40 and 25, &c.

The reflecting Telescope.—We apply the term *Telescope,* to all instruments serving to show distant objects magnified. It consists of a concave mirror or a converging lens, by which an image of distant objects is produced, which is seen through a simple or compound eye-glass, or eye-piece. If the image be reflected by a concave mirror, we term the instrument a reflecting telescope. Its most important part is a concave mirror of metal turned towards the object, of which an inverted image is produced in accordance with the laws we have already treated of. Different telescopes vary only in the manner in which this image is observed.

The most common arrangement adopted in the construction of these telescopes is represented in Fig. 304. The concave mirror $m\ m'$ has a circular aperture $c\ c'$ in its centre; the incident rays are so reflected that a real inverted image of distant objects is formed at $i\ i'$; this image is now within the focal distance of the small concave mirror v, by which an upright image of the inverted image $i\ i'$ is formed before the eye-glass. The eye-glass is composed here as in the microscope, of two lenses. The first causes the rays passing from the mirror v to be more convergent, and consequently moves the image $n\ n'$ somewhat nearer to the mirror v, than would be the case if it were not for this lens; the image $n\ n'$ is now seen through the lens immediately before the eye.

FIG. 304.



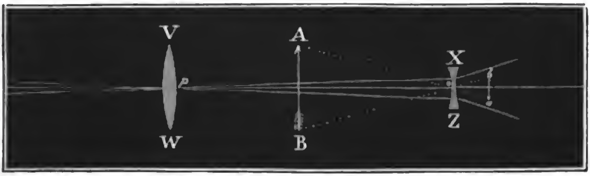
The mirror v must be removed from, or drawn nearer to the eye-glass, in proportion to the greater or smaller distance of the objects to be observed; this is effected by the screw $b\ s$.

Refracting Telescopes.—In some telescopes, a converging lens is used in the place of the concave mirror. An achromatic lens should be chosen, in order that the image of distant objects thrown upon the object-glass may be clear and sharply defined; such an object-glass must, therefore, always be composed of two unequally dispersive substances; two lenses being generally used that are in immediate contact, as we have already described; but in dialithic telescopes, the achromatising flint-glass lens is removed further from the front crown-glass lens, and brought nearer to the ocular, so that the former may have a smaller diameter. Teles-

copes differ in the various arrangements of the ocular. In Galileo's telescope, the ocular consists of a simple biconcave lens; the ocular of the night, or astronomical telescope, has one or two converging lenses; while the terrestrial telescope has four.

The arrangement of Galileo's telescope is represented in Fig. 305. *V W* is the object-glass, which would produce a dimi-

FIG. 305.



nished inverted image at *a b*, if the rays were not already received by the concave glass *X Z*. But now the eye-glass is so placed that the distance of the image *a b*, is somewhat greater than the dispersive distance of the concave lens; consequently, all rays converging towards one point of the image *a b*, are so refracted by the concave lens that after their passage through it, they diverge as much as if they came from a point before the glass; the rays converging towards *b* diverge, therefore, as if they came from *B*; and those converging towards *a*, as if they came from *A*; we thus see the erect magnified image *A B* through the telescope.

It is easy to calculate the magnifying power of this kind of telescope, if we know the focal distance of the object-glass and the amount of dispersion of the eye-glass. The angle under which the object would appear without the telescope is equal to the angle under which the image *a b* appears when seen from the focus of the object-glass, and is consequently equal to the angle *b p a*; if we suppose the eye removed to the focus *o* of the eye-glass, the object seen through the telescope will appear under the angle *A o B*, which is equal to the angle *b o a*; in order, therefore, to determine how many times a telescope magnifies, we have only to determine how many times the angle *b o a* is greater than the angle *b p a*.

The distance of the image *a b* from the object-glass is equal to the focal distance *f* of the latter, if the object be very far removed; but the distance of the image *a b* from the ocular, is not perceptibly larger than the dispersive distance *f'* of this glass, and we may, therefore, without any serious error consider the distance of

the image $a\ b$ from o as equal to f'; but now the angles $b\ p\ a$ and $b\ o\ a$ are inversely very nearly as this distance, therefore:

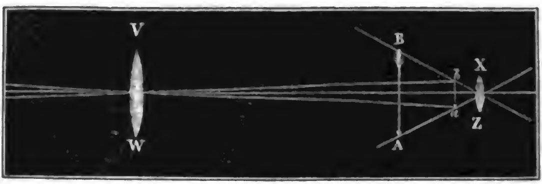
$$b\ p\ a : b\ o\ a = f' : f, \text{ or } \frac{b\ o\ a}{b\ p\ a} = \frac{f}{f'}.$$

If we consider the angle $b\ p\ a$, under which the object appears without a telescope, as $= 1$, we shall have $b\ o\ a$, the angle under which it will be seen in the telescope $= \frac{f}{f'}$; that is, we shall find the magnifying power by dividing the focal distance of the object-glass by the dispersive (or focal) distance of the eye-glass: the magnifying power increases, therefore, directly with the augmentation of the focal distance of the object-glass, and inversely with the dispersive (or focal) distance of the eye-glass.

The distance of the two glasses is evidently very nearly equal to $f - f'$; if, therefore, we join different eye-glasses to the same object-glass, the distance of the two glasses must be greater in proportion to the shortness of the focal length of the eye-glass, and therefore to the increase of the magnifying power.

In astronomical telescopes the image of the object-glass is actually formed, and is seen through a simple or compound lens, as represented in Fig. 306; $a\ b$ is an inverted image, formed by

FIG. 306.



the object-glass $V\ W$, of an object which is examined by the lens $X\ Z$, and appears magnified at $A\ B$.

The magnifying power of such a telescope can easily be calculated, if we know the focal length of the object-glass and the eye-glass, for the angle of vision under which the object appears to the naked eye is equal to the angle under which the image $a\ b$ is seen from the middle of the object-glass $V\ W$; but it appears through the telescope under the same angle as the image $b\ a$, seen from the middle of the eye-glass $X\ Z$; but the one of these angles is to the other inversely as the distance of the image $a\ b$ from the object-glass to the distance from the eye-glass; and the image is

at the focal distance f from the object-glass, and at the distance f' from the eye-glass, if we designate the focal distance of the eye-glass by f'; the angle of vision under which the distant object appears when seen through the telescope, is to the angle of vision under which it is seen by the naked eye as f to f'; the magnifying power of the telescope is therefore $\frac{f}{f'}$.

The length of the telescope is $f + f'$; that is, it is equal to the sum of the focal distances of both glasses.

In general a combination of two lenses is made use of instead of one simple lens for the eye-glass. The compound eye-pieces of astronomical telescopes are either arranged precisely like the compound eye-pieces of the microscope—in which case the image is formed between the two glasses of the eye-piece—or the two lenses are placed near to each other, so that the image is formed before the eye-piece, and is seen through both lenses as through one single strong one.

It is evident that we see the objects inverted through an astronomical telescope, for an inverted image of the distant object is formed upon the object-glass, and from being seen through a simple magnifying glass does not again appear erect.

The clearness of the image depends upon the aperture of the object-glass, and the extent of the field of view upon the eye-glass.

In order to be able to bring the objects to be observed within the field of view of astronomical telescopes, a cross wire must be applied, exactly at the spot where the image of the object appears through the object-glass.

Although it is inexpedient in looking at terrestrial objects to see everything inverted, it matters but little in astronomical observations, or in making measurements. In order to see objects erect when they are very strongly magnified, the eye-glass of the astronomical telescope is replaced by a tube containing four convex lenses, and we thus obtain the *terrestrial telescope.* The four lenses in the eye-piece form, in some degree, a magnifying compound microscope of inconsiderable power, by which the inverted image is made to appear erect. The two anterior glasses in the eye-piece form, in some respects, the object-glass of this microscope, while the two others constitute the eye-glass.

The magnifying powers of the Galilean and the astronomical telescopes may be calculated, as we have already seen, by the

focal distances of the glasses; but as this focal distance has first to be ascertained, it is better to determine the amount of magnifying power by immediate experiment. This may be simply done in the following manner: we place at some distance from the telescope a graduated staff, such as is used in measuring land, and while we keep one eye directed to this, we look through the telescope at the same time with the other; we thus observe how many divisions of the graduated staff seen by the naked eye fall upon one of the degrees magnified by the telescope, and consequently obtain the value of the magnifying power. The rows of tiles of a roof will answer a similar purpose to that of the graduated staff.

Formerly dioptric telescopes were very imperfect, as achromatic object-glasses had not then been applied in practice; and on that account a concave mirror was made use of instead of the object-lens, and thus arose the reflecting telescope.

CHAPTER V.

PHENOMENA OF INTERFERENCE.

Two different hypotheses have been advanced to explain the different phenomena of light, namely, the theory of *Emission*, or *Corpuscular* theory, and the theory of *Vibration*, or *Undulatory* theory.

The theory of emission assumes that there is a peculiar substance of light, and that a luminous body transmits particles of this fine substance in all directions with such velocity, that a particle of light travels from the sun to the earth in 8 minutes 13 seconds. This substance of light must necessarily be extremely attenuated, and not subject to the action of gravity, consequently it must be considered as imponderable. The difference of the colours of light rests upon the difference of the velocity of transmission; reflection is, therefore, according to this view, analogous to the rebounding of elastic bodies. To explain refraction according to this theory, we must assume, 1. That there are in transparent bodies interstices sufficiently large to allow of the passage of particles of light; and 2. That ponderable molecules exert an attractive influence on the particles of light, and that this combined with

the velocity attained by the particles of light, occasions their deviation from their direct course.

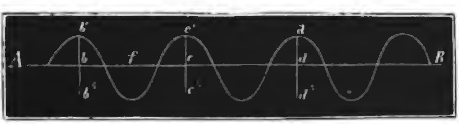
The theory of Vibration assumes, that light is propagated by the vibrations of an imponderable matter termed *ether*. According to this theory, light is somewhat similar to sound; sound, however, is transmitted by the vibrations of a ponderable substance, while light is propagated by the vibrations of an imponderable one—ether. This *ether* fills the whole universe, since light penetrates the spaces of heaven. This imponderable substance is not only distributed through the otherwise vacant space separating the stars, but it penetrates all bodies, filling up the interstices occurring between ponderable atoms. If the *ether* were in a state of rest throughout the whole universe, there would everywhere be darkness; but put into vibration, as it were, at one spot, the waves of light are propagated in all directions, as the vibrations of a chord are transmitted through a calm atmosphere. Light which first arises from motion is, therefore, to be distinguished from the ether itself, as the vibratory motion producing sound is to be distinguished from the vibrating particles of ponderable matter.

For a long time both theories numbered adherents amongst eminent men of science. *Newton* established the theory of emanation, and *Huyghens* may be considered as the founder of the theory of undulation. The fundamental study of the phenomena of light, which we are about to treat of, has afforded a decided triumph to the theory of undulation, for these phenomena admit of a very simple explanation by the hypothesis of air-waves, but not so by the theory of emission.

Elements of the theory of Undulation.—The particles of a luminous body vibrate in a manner similar to those of sonorous bodies, only the undulations of light are infinitely more rapid than those of sound; they are not, however, transmitted by ponderable matter, but by the luminous ether.

If a ray of light be transmitted in the direction from *A* to *B*, Fig. 307, all the particles of ether lying in a condition of equilibrium, upon the straight line *A B*, vibrate in directions at right

FIG. 307.



angles to $A\ B$, in almost the same way as do the parts of a tense line, sharply struck at one end. The curve in Fig. 307 represents the mutual position of the vibrating molecules in a definite moment of their motion.

Let us now consider the vibrations of a molecule of ether somewhat more closely. The particle whose position of equilibrium is at b, vibrates continually between the points b' and b''. At b' its velocity is null; the more, however, the particle approaches the position of equilibrium, the more its velocity increases, until this attains its maximum at the moment in which the molecule passes its position of equilibrium; from this time, the velocity again diminishes until it is again null at b'', on which the motion begins in an opposite direction.

Although light travels with extraordinary rapidity, its transmission is not instantaneous; the vibrations of a molecule of ether are not, therefore, instantaneously transmitted in the direction of the ray to the succeeding molecules. Let us suppose the whole series of molecules on the line $A\ B$ to be at rest. If now the molecule b begin its vibrations at a definite moment, all the other molecules lying further beyond B will begin to vibrate later in proportion as they are removed from b; whilst the molecule b makes a perfect vibration, that is, whilst it moves from b' to b'' and back again towards b', motion will be transmitted to some one molecule, as c, so that the latter will begin its fresh vibration at the same moment in which b begins its second motion. From this time, the molecules b and c will constantly be in the same phase of vibration, that is, they will simultaneously pass the position of equilibrium moving towards the same side, and will simultaneously attain the maximum of deviation on either side of $A\ B$.

The distance $b\ c$ between two molecules of ether constantly in the same phase of vibration, is termed, as we have already seen, the *length* of a wave. If $c\ d$ be also the length of a wave, the molecule will begin its first vibration at the moment in which c begins its second, and b its third oscillation; d will from this time be constantly in the same phase of vibration as c and b.

If f lie half-way between b and c, that is, if it be removed half the length of a wave from b, the molecule at f will always be in phases of vibration opposite to those of the molecules at b and c. When b and c attain the maximum of deviation above $A\ B$, attains the same maximum on the opposite side. The molecule f passes the position of equilibrium simultaneously with b and c, but moves in an opposite direction.

If two molecules of ether be removed ½ the length of a wave from 'h other in the path of a ray of light, they will always be affected equal but opposite velocities. The same applies to such par- les as are removed $\frac{3}{2}$, $\frac{5}{2}$, $\frac{7}{2}$, &c., of the length of a wave.

The length of a wave is not the same for different colours; it largest for the red, and smallest for the violet. We cannot at further here of the manner in which the length of waves for ferently coloured rays may be determined with extraordinary :uracy.

Unequal periods of undulation and different lengths of waves are endant upon each other; thus the undulations of violet rays are quickest, and those of the red rays the slowest.

We thus see that in light the difference of colours corresponds h the unequal height and depth of tint.

We may form a very clear idea of the manner in which waves of ht are distributed in all directions from a luminous point, if, as have already shown, we consider the waves that arise upon the face of a piece of still water on the throwing in of a stone. From spot where the stone sinks in the water, circular waves are med; the advance of these waves from the central point of motion s not depend upon the separate particles of water having such a gressive motion, for if a light body, as a piece of wood float upon it hin the boundary of the undulatory motion, it will only rise and l alternately. The particles of water move alternately up and wn at the spot where the stone fell into the water, and this motion transmitted in a circle with equal velocity; all the particles water, therefore, which are equi-distant from the middle int, will also be in like phases of vibration; that is, they will multaneously reach their highest and lowest position. Concentric ve-elevations and depressions will, therefore, be formed, as is wn in Fig. 308. If at a definite moment, the complete circles correspond to the wave elevations, and the dotted circles to the wave depressions, the wave elevations will spread outward in such a manner as to be after a short period of time exactly at the dotted axis, while the wave depressions will have in like manner assumed the places defined by the complete circles.

FIG. 308.

All the particles of water intervening

between two successive wave-elevations or wave depressions form a wave, while length of the wave is the distance from one elevation to another, or from one depression to the next. As one particle of water descends at *a*, for instance, from its highest position, and then rises again to the summit of a wave-elevation, the latter will advance one length of a wave.

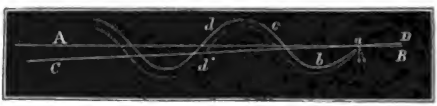
As the waves of water distribute themselves in concentric circles around the point of displacement, the undulations of light move in concentric spherical layers around the source of light; the *surface* of the *waves of light* is spherical, at least as long as the elasticity of the ether remains the same in all directions.

Interference of rays of light.—We will at once proceed to explain how the combined action of two pencils of light sometimes produces increased light, and sometimes perfect darkness.

Such an increase or cessation of light produced by the combined action of two rays of light is designated by the term *interference* of the rays of light; and may be thus explained.

In Fig. 309, the lines *A B* and *C D* represent two elementary

FIG. 309.



rays of light, which, emanating from one source, reach the point *a* by different paths, and intersect each other at a very acute angle. If the distance traversed by the ray of light *C D* on its path from the source of light to the point *a* be as great, or 1, 2, or 3 lengths of a wave greater than the length from the source of light to the point *a* on the path of the other ray, the two rays will interfere at *a* in the manner represented in Fig. 311.

The wave line *a b c d* represents, at a given moment, the relative position of the particles of ether transmitting the rays in the direction *A B*. The particle *b* has just reached its extreme external position below *A B*, and the particle *a* passes its point of equilibrium in the direction indicated by the little arrow.

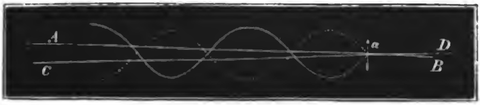
The dotted wave line shows us the simultaneous state of vibration of the particles of air propagating the pencil of light *C D*. If both rays have traversed equal distances from the source of light to the point *a*, the particle *a* will be affected simultaneously in the same way by both rays; at the moment represented in our drawing, the particle *a* is likewise forced downward by the second

wave system, the intensity of vibration is, therefore, twice as great as if its motion were only influenced by the vibrations of one ray of light.

In like manner the vibrations of two rays of light meeting at one point, and deviating throughout their whole course about the multiple of a whole length of a wave, must strengthen each other.

Fig. 310 represents the combined action of two rays, one of

FIG. 310.



which has preceded the other by an odd multiple of a half a length of a wave. By the vibrations of the one ray (the wave-line corresponding to it is fully delineated, while that of the other ray is only dotted) the particle *a* is urged upwards at the same moment in which the undulations of the other ray strive to move it downwards with equal force, the two opposite forces, therefore, neutralize each other, and the particle *a* remains at rest.

We have hitherto only considered those cases in which the difference of the interfering rays amounts to the multiple of a whole length of a wave, or to an odd multiple of a half the length of a wave. If the difference falls within these limits, an effect will be produced by the interference of the two rays lying between the limits of which we have already spoken, that is, there can neither be any complete destruction of the undulation, nor any doubling of the intensity of the undulation. The actual intensity of undulation produced, approaches more to one or other of these limiting values, according as the difference of the path approximates more nearly to an odd multiple of a half a wave, or to a multiple of the whole length of a wave.

We now pass to the consideration of those phenomena which admit of being referred to the principle of interferences.

Refrangibility of light.—If we look at a little solar-image on the inside of a blackened watch-glass, a polished metal button or a thermometer bulb by means of a fine circular opening, as may be made with a fine needle in a card, we see a light round spot surrounded by several coloured rings. Fig. 312 represents this phenomenon.

If instead of the point, we make a fine straight slit in the card,

FIG. 311.

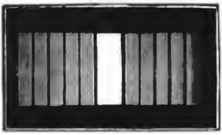


FIG. 312.

and look through it at the solar image upon the watch-glass, or (which is better) upon the light line on a glass tube blackened in the inside, and laid in the sun, we shall see the phenomenon exhibited at Fig. 311. In the centre of the image we shall see a light stripe, having at both sides narrower coloured stripes which have a less intensity of light as they approach the outside.

The finer the circular opening, and the narrower the slit, the broader will be the rings or the stripes as the case may be.

The simplest mode of observing this phenomenon is by holding a glass of only one colour, a red one for instance, to the eye with the card; then on looking through the slit we shall see in the centre a bright red stripe bounded on both sides by a black stripe; on either side there will then succeed several red lateral images which always become fainter, the one being divided from the other by a black stripe, nearly in the manner represented in the undermost series in Fig. 315.

The bright sides as well as the bright stripe form the same colour in the middle, they are not sharply defined by the black stripes, the transition from clear light to the darkest spots is, therefore, gradual.

We see the same phenomenon through a green glass, only in this case the stripes are narrower, and when a violet glass is used they are still more so, as indicated in Fig. 313. The explanation of these phenomena can only be here cursorily touched upon.

FIG. 313.

If the light fall from a sufficiently remote point straight upon the plane of the screen *A B* in which there is the opening *C D*, we may consider all the particles of ether at this opening as equally remote from the source of light, and, therefore, in like

hases of vibration. But each one of these particles of ether transmits its vibrations on the further side of the screen in all directions, as if it were a self luminous particle; the intensity of the light at any one point *s* lying behind the screen depends, consequently, upon the action produced by the interference of all the rays emanating from the different points of the opening *C D* and meeting at *s*.

FIG. 314.

The rays of light which are transmitted from *C D*, at right angles to the pening, will always strengthen each other, consequently the centre f the image will be bright. If, however, we pass over to points ying at the side, the rays meeting here will not strengthen each ther; the intensity of light must, therefore, diminish laterally owards a point at which all the rays coming from *C D*, and neeting here, will entirely destroy each other; here we shall bserve a dark stripe.

Still further from the centre there are again points at which no omplete destruction of the waves proceeding from *C D* and neeting here occurs, where consequently light is again observed; o this succeed darker stripes by which all the waves of light erfectly destroy each other. The reason of the light and dark tripes not coinciding in the differently coloured rays depends upon he difference of the lengths of their waves.

When all the differently coloured rays combine, when, for nstance, we look at the white solar image through a fine perture without the assistance of a glass, we shall see a white treak in the centre, because here the maximum of the intensity of ght for all colours is found; but the side images are all coloured, here being nowhere a perfectly white or perfectly black stripe to e seen, for where there is a black stripe for one colour, there will e a light stripe for other colours.

We have here only slightly touched upon the explanations ecessary to elucidate the phenomena of refrangibility, since a uller exposition of the question would carry us beyond our limits.

The form of the phenomena of refrangibility depends upon the orm of the apertures; and also changes with the number of the atter.

If two minute circular apertures in a screen lie near each other,

as thus . ., we shall again see on looking towards a luminous point the same rings (Fig. 312) as if there were only one aperture; these rings appear, however, to be intersected by straight black stripes lying at right angles to the direction of the line uniting both openings. These black stripes also pass through the central light spot, Fig. 312.

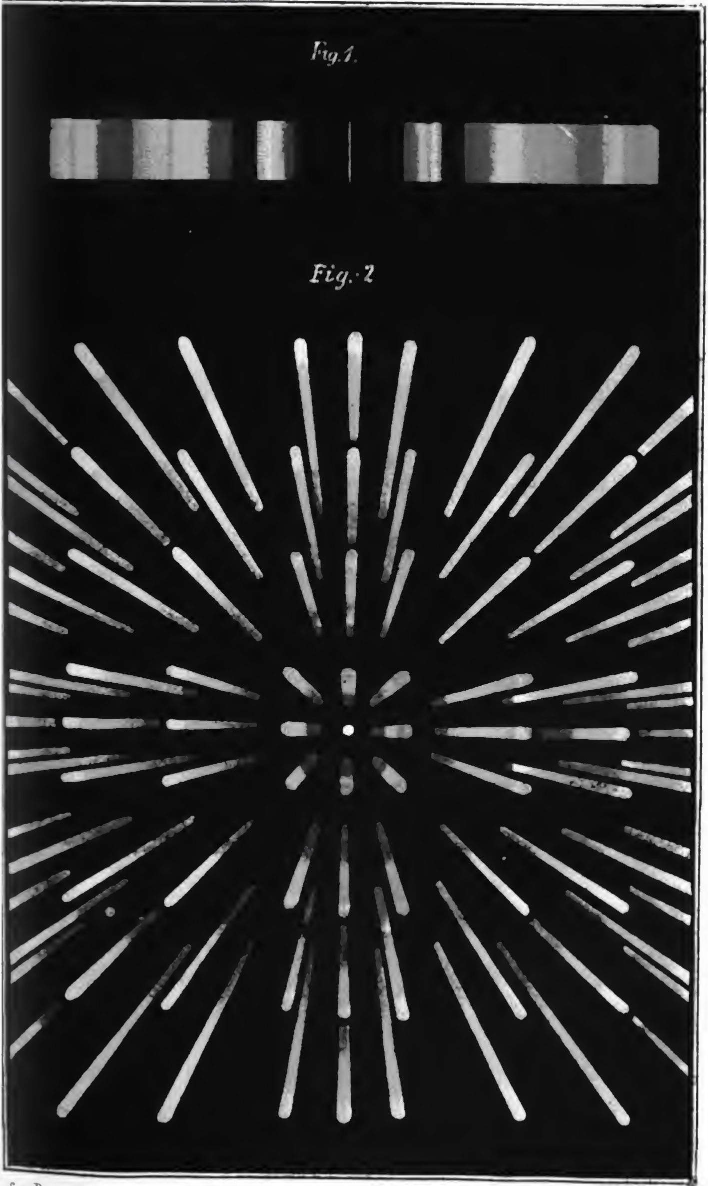
This experiment clearly shows, that darkness may arise from the combination of two rays of light, or in other words, that the action of one ray of light may be destroyed by that of another. If the light enter only through one hole, we shall see the figure represented in Fig. 312; as soon, however, as a second aperture is added, black stripes will appear in the bright parts of this image; here, therefore, the action of light produced by rays incident at one aperture will be destroyed by that of the rays passing through the other aperture.

Very curious phenomena are observed in suffering white light to pass through a wire gauze—this is exemplified in the frontispiece in Fig. 1, Plate I. In the centre appears the direct image of the line of light, it is white, owing to the combination of the maxima of all the colours. On either side of this line of light are dark spaces, to which succeeds a coloured band similar to the prismatic spectrum, whose violet extremity is turned inwards. After a second totally dark space comes another broad coloured band, the red extremity of which touches upon the violet extremity of a third coloured band.

Fig. 2, Plate I, also exhibits the phenomenon observed through simple gratings, when two of these are crossed before the object-glass of a telescope, while we direct it towards a luminous point. The middle is occupied by the white image of the luminous point, while around are a number of prismatic images, which all turn their violet extremities inward.

Very beautiful phenomena of refrangibility are manifested as seen through a series of fine apertures, as, through a row of fine parallel lines scratched upon a glass plate. To this class belong the phenomena seen on looking towards a luminous point through the feather of one of the smaller kinds of birds, the flame of a taper suffices to show this with great brilliancy.

If we strew lycopodium seed upon a glass plate, and look through it towards a lighted taper, we shall see a beautiful areolar figure composed of many coloured rings. This is also a phenomenon of refrangibility.



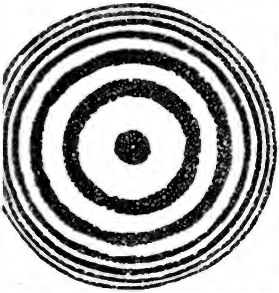
See Page 296.

Madeley Lithog. 3 Wellington St. Strand

Colours of thin plates.—Every transparent body appears vividly oured, if seen in sufficiently thin plates, as is well exhibited in ıp-bubbles. The thin pieces of a glass sphere expanded to rsting before the glass-blower's lamp exhibits itself in the st dazzling colours; similar colours are observed when a drop oil (as oil of turpentine) is spread over a surface of water; or ıen a glittering piece of metal heated in the fire is gradually vered with a coating of oxide (in the annealing of steel). Thin yers of air produce such colours as these, as may be often seen the flaws in somewhat thick masses of glass.

These colours are exhibited with the greatest regularity in the form of rings,* if we lay a glass lens of great focal length upon a plate of glass, or the plate of glass upon the lens. Newton, who observed these coloured rings, which are commonly termed Newton's rings, used lenses whose radii of curvature amounted from 15 to 20 metres. Where the plate of glass touches the lens, we see by reflected light a black spot surrounded with coloured concentric ngs, becoming narrower and fainter towards the outer edges, as en in Fig. 315.

FIG. 315.



If we look at the rings through a monochromatic glass, we only e alternately bright and dark rings. These rings are broader r red than for green light, and narrower for violet than for green. f, instead of coloured we use white light, we shall not be able to e a thoroughly white, or a thoroughly black ring, because neither he light nor the dark rings of the different colours coincide; we ee colours throughout, which instead of being the pure hues of he spectrum are mixed colours.

These phenomena of colour may be explained in the following nanner:

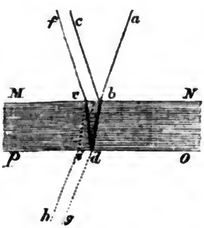
If rays of light fall upon any lamina of a transparent body, they vill be reflected partially at its upper, and partially at its lower urface, and the rays of light reflected from the two surfaces will

* The ring system is most beautifully exhibited in several uni- and bi-axal rystals, and for the sake of more striking illustration of these phenomena, we have iven coloured representations of the appearances manifested, which will be found in Plate II.

interfere, either destroying or strengthening each other, according to the difference of the paths which they have traversed.

Let us consider this more closely. In Fig. 316, *M N O P* represents a thin lamina of a transparent body on which a pencil of parallel rays *a b* impinges, this pencil of rays will be partially reflected in the direction *b c*, and partially refracted towards *d*. But the refracted rays will suffer a second separation at the surface *O P*; the reflected portion will emerge at *e*, in the same direction as the pencil of light reflected at the first surface *M N*, consequently both pencils of light, *b c* and *e f* will interfere.

FIG. 316.



But how happens it that only thin lamina exhibit such colours as these, while plates of some thickness do not manifest them? Let us, for the sake of more easy concession, assume that the waves of light in violet rays, are half as great as those in red rays; (they are actually somewhat beyond half as great), then the diameter of the violet rings will be the half of that of the red rings; at the place where the first dark ring for red light is situated, there will be also the second dark ring for violet light, and one light ring for a colour lying nearly in the middle between the red and the violet; this colour is decidedly predominant at this spot.

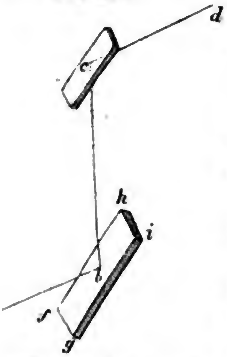
Where the seventh dark ring for red light occurs, there will be the fourteenth dark ring for violet light; at this spot, there will, therefore, still be six dark rings, and seven bright rings for the intermediate colours. If, therefore, the extreme red, the boundary between red and orange, between orange and yellow, yellow and green, green and blue, blue and indigo, indigo and violet, and the extreme violet be at the minimum, the intermediate rays of red, orange, yellow, green, blue, indigo, and violet will be at the maximum; no one of these colours can, therefore, predominate, and combined they will yield white.

By transmitted light, thin plates also show similar, but far fainter colours, which are complementary to those exhibited by reflected light.

Polarization of Light.—If we cut from a transparent crystal of tourmaline a plate whose surface runs parallel to the principal axis, and if we look through it towards a polished plate reflecting the light of the sky towards the eye at an angle of from 30°

0⁰, the polished surface will appear bright or dark, according re turn the section of the tourmaline; it will not, therefore, in y position suffer the transmission of the rays reflected from plate. The pencil of light must, therefore, by its reflexion n the polished plate, have undergone a peculiar modification, ch we designate by the term *polarization.*

FIG. 317.



If we had, under similar circumstances, examined the rays reflected from the glass plate with the plate of tourmaline, we should have observed the same phenomenon, consequently rays of light are polarized by reflexion from a glass surface.

The tourmaline plate may be replaced by a glass mirror.

If an ordinary ray of light $a\ b$ fall upon a plane glass plate $f\ g\ h\ i$ at an angle of $35^0\ 25'$, it, for the most part, becomes reflected in the direction $b\ c$, ording to the usual laws. The ray reflected in the direction $b\ c$, now *polarized* by this reflection. These phenomena can be t observed when the mirror $f\ g\ h\ i$ is blackened on the reverse e, for besides the rays polarized by reflection, some coming m objects under the mirror are also transmitted in the direc- n $b\ c$, and which have passed through it.

If the ray $b\ c$, polarized by reflection, fall upon a second glass te, likewise blackened upon the reverse side, and parallel to : under one, the ray $b\ c$ will also make an angle with it of ', and the plane of reflection of the upper mirror coincide h that of the lower one. In this position of the second mirror, : ray $b\ c$ is reflected like every ordinary ray of light; if, however, turn the upper mirror in such a manner that the direction of : ray $b\ c$ forms the axis of rotation, the angle made by the ident ray $b\ c$ with the plane of the mirror will remain the same, t the parallelism of the two mirrors will cease, and the plane of lection of the upper mirror no longer coincide with that the lower. If now we turn the upper mirror from its position parallelism with respect to the other mirror, the intensity of the ice reflected rays will diminish the more the angle which is ade by the plane of reflection of the upper mirror with that the lower increases until it becomes 90^0, or in other words,

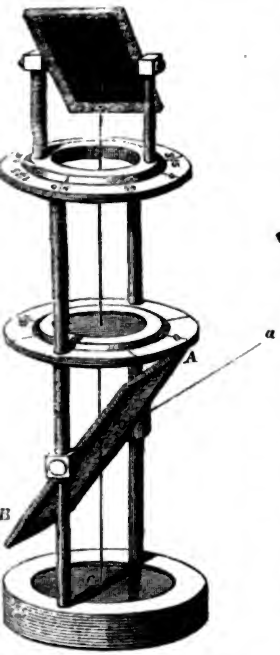
until the planes of reflection of both mirrors are at right angles to each other. In this position the ray *b c* will be no longer reflected from the upper mirror, as would be the case if *b c* were an ordinary ray of light. By the continued turning of the upper mirror, the intensity of the reflected ray gradually increases, until it again attains its maximum on the rotation amounting to 180°. In this position the planes of reflection of the two mirrors will again coincide. If we turn it still further, the ray reflected to the upper mirror will again become fainter, disappearing entirely when the planes of reflection of both mirrors again cross each other, consequently when the rotation amounts to 270°, &c.

An arrangement by which two such mirrors can be used, and by which the above described experiments may be made, is termed a polarizing apparatus. The simplest arrangement that can be adopted, is the following: A mirror blackened at the back is so fastened to one end of a metallic or wooden tube, that it makes an angle of 35° with the axis of the tube, when all the rays, incident on the mirror at an angle of 35°, are so reflected that they pass through the tube in the direction of this axis. At the other end of the tube there is a ring, whose axis corresponds with that of the tube, and which therefore admits of being turned round upon a plane, at right angles to this axis. To this ring is fastened a second mirror, blackened in like manner as the other, and also making an angle of 35° with the axis of the tube. By turning the ring, the mirror is made to revolve with it, and may thus be brought into all the positions we have just mentioned.

Such a polarizing apparatus is, however, very inconvenient; and that delineated in Fig. 318, and represented at one fourth of its natural size, is far better in every respect. Two rods are inserted diametrically opposite to each other, in the rim of a stand, which must be made sufficiently heavy to give the whole the stability necessary to support the apparatus; between these rods there is a frame *A B*, enclosing a polished glass mirror. This frame, together with the mirror, may be made to revolve in a horizontal axis by means of a pivot, by which means the glass may be moved at will in any position about the direction of the perpendicular. The mirror is generally, however, placed in such a position that its plane shall make an angle of 35° with the vertical. If, in this position of the mirror, a ray of light *a b* falls upon it at an angle of 35°, it passes partially through the glass, (but

this we need not take any account), and is partially reflected vertically downwards in the direction $b\ c$. This reflected ray is now polarized, and a vertical plane passing through the lines $a\ b$ and $b\ c$, is its *plane of polarization.*

FIG. 318.



At the base of the apparatus there is a common mirror, blackened beneath, and horizontally placed, on which the polarized rays $b\ c$ impinge rectangularly; this ray is, therefore, reflected in the same direction in which it came, and passing through the polarizing mirror proceeds, in a vertical direction, to the upper part of the apparatus. The upper extremities of the columns (we will not at present treat of the middle part of the apparatus) have a graduated ring. The zero of this division is so situated that if we imagine a vertical plane drawn through 0 and 180°, it will coincide with the plane of reflection of the lower mirror, and consequently with the plane of polarization of the rays olarized by it. Within this graduated ring, there is another that an be made to revolve, and on which are placed two columns, iametrically opposite to each other, having between them a iirror of black glass, or a mirror blackened on the back, which fastened in the same manner as the lower polarizing mirror; as he lower one is made to revolve round a horizontal axis, the lackened mirror may easily be so placed as to make an angle f 35° 25′ with the vertical.

The revolving ring on which the columns stand, slopes somewhat at the edges, while in the centre of the anterior half of the ing, an index is drawn upon the slope. A vertical plane passing hrough this index to the middle point of the ring, coincides with he plane of the reflection of the blackened mirror. If we turn he ring bearing the upper mirror, so that the index coincides with the 0 of the graduated lines, the planes of reflection of the upper and lower mirror will coincide. The same will be the case

when the index stands at 180°. If the index stand at 90°, as in our figure, or at 270°, the plane of reflection of the upper mirror will form a right angle with the plane of reflection of the lower mirror.

The phenomena of ordinary polarization, which may be observed by this apparatus, are as follows. If both mirrors lie parallel to each other, if, therefore, the index of the ring bearing the black glass, stand at 0°, the upper mirror will reflect the rays impinging upon it from below, and the field of vision appear consequently clear. If we turn the analysing mirror (this is the common term for the upper mirror) from its position, the intensity of the light reflected by it will diminish more and more until it comes at last to 0, when the index will stand at 90°. In this position, therefore, the blackened mirror no longer reflects the rays impinging upon it from below, and the field of vision appears dark. If we turn it still further, it becomes gradually lighter, and when the index stands at 180°, the intensity of the light is again equal to what was observed at 0°. The light, however, diminishes again when we turn the mirror beyond 180°, and the field of vision becomes a second time dark when the index stands at 270°.

It is of course evident that during this rotation, the direction of the blackened mirror must remain unchanged with respect to the vertical. But in all positions, the upper mirror makes an angle of 35° 25′ with the vertical. If without altering anything else in the apparatus, we change the position of the lower mirror with regard to the incident rays, if, for instance, we place it so as to make an angle of 25° with the vertical, those rays will reach the upper mirror of the apparatus which have made an angle with the lower mirror. If we repeat the above experiment, we shall find that the light reflected from the upper mirror is never quite null. If the upper mirror be so placed that its plane of reflection cross that of the lower one, if, therefore, the index of the lower division stand at 90°, although less light will be reflected in this position than in any other, still some portion of the rays coming from below will be reflected.

We may conclude from this, that the rays reflected from the lower mirror are only partially polarized at an angle of 25°. The more the angle, which the rays incident upon the lower glass mirror make with its plane, deviates from 35° 25′, the more imperfect is the polarization. The angle at which perfect polarization takes place (viz. 35° 25′ for glass), is termed the angle of polarization.

tallic surfaces have not the property of polarizing light by ection; we cannot, therefore, use mirrors plated on the back h tin and quicksilver for experiments in polarization.

l'he polarization of light is explained according to the undulatory ory, on the hypothesis that all the undulations of a polarized ray light occur in one and the same plane, whilst the undulations of ordinary ray of light take place in every possible line at right gles to its direction.

Double refraction.—If we place a rhombohedron of Iceland spar on a piece of paper, on which a black point or line has been wn, we shall see this point or line double. If we form a prism this spar, we shall see a double image of every object looked at. is experiment proves that every ray of light impinging on a sm of Iceland spar is divided into two portions, which do not y the same laws of refraction, and that this spar has the operty of double refraction.

If we examine through a plate of tourmaline the two objects n by means of the Iceland spar, we shall find that both rays are larized, for according as we turn the plate of tourmaline, one or her of the images will disappear; the plane in which the particles one ray vibrate is at right angles to the plane of vibration of at of the other ray.

Iceland spar is not the only doubly refracting body; this operty belongs to all crystallizable substances not belonging to gular systems of crystallization.

In every doubly refracting crystal, there are one or two direcons in which double refraction does not take place; these rections are termed the *optical axes*.

A development of the laws of double refraction would lead us yond our limits. If we lay a very thin plate of crystallized psum upon the middle circle of the polarizing apparatus, seen Fig. 318, it will appear coloured, changing (other circumstances maining the same) its colour with the thickness of the plate.

If a thin plate when laid between mirrors crossing each other ows a definite colour, the colour complementary to it will appear hen these mirrors are parallel.

These phenomena of colour arise from the two rays into which e incident light is separated (for crystals of gypsum are doubly efracting) traversing the plate with equal velocity and interfering fter reflection from the upper mirror.

Plates of other crystals exhibit similar colours when made sufficiently thin.

If we cut a plate from a doubly refracting crystal, whose surface is at right angles to the optical axis, it will show, when brought into the polarizing apparatus, or laid between the plates of tourmaline, very beautifully coloured rings, the formation of which may be explained in the same way as the colours of the plates of gypsum.

CHAPTER VI.

CHEMICAL ACTIONS OF LIGHT.

Influence of light on chemical combinations and on decompositions.—At an ordinary temperature, chlorine and hydrogen gases do not combine with each other in the dark; but as soon as we give admittance to light, the combination takes place, slowly by simple daylight, but is accompanied with an explosion when exposed to direct sunlight. Chlorine absorbed by water has the power of gradually withdrawing the hydrogen from it only when exposed to the action of light; phosphorus kept in water is converted when exposed to the sun into the red oxide of phosphorus. At ordinary temperatures concentrated nitric acid is partially decomposed by light into oxygen and nitrous acid; white chloride of silver becomes first coloured violet by the action of light, and subsequently quite black, and a portion of the chlorine escapes, &c. These are only a few of the most striking instances, adduced to show the influence of light upon chemical combinations and upon decomposition, and all chemical treatises afford numerous examples of the same thing.

The influence of light upon the decomposition of organic substances is very remarkable; for instance, it promotes the union of the oxygen of the atmosphere with the carbon and hydrogen of organic substances; hence arises the fading of vegetable colouring matter in light, especially in sunlight; the yellow coloration of oil of turpentine, and the green hue of yellow guaiacum on exposing to light a piece of paper dipped in a spirituous solution of thin gum resin, &c. Light is absolutely necessary to the vigorous growth of living plants, their perfect development being impossible in the dark, where they soon acquire a sickly appearance, and their leaves and blossoms grow pale. Plants reared in a room, always incline towards the windows. The green portions of plants absorb carbonic acid from the air; this carbonic acid is decomposed, the

carbon remaining as a constituent of the plants, whilst the oxygen is again given off to the atmosphere. This decomposition of carbonic acid and exhalation of oxygen into the air takes place only under the influence of light. We may easily convince ourselves of this fact by laying a fresh green twig under a glass bell filled with water holding in solution carbonic acid; in the light numerous gas bubbles develope themselves upon the leaves, and rise in the upper part of the glass bell; the gas thus collected is carbonic acid gas. This development of gas does not take place in the dark, and ceases as soon as all free carbonic acid is removed from the water.

The chemical actions of the blue and violet rays are generally much stronger than those of the red.

Photography.—The idea first occurred to *Wedgwood* to avail himself of the blackening of chloride of silver to fix the pictures of the *Camera Obscura*, and *Davy* obtained the images of small objects on chloride of silver paper by means of a solar microscope; but these were soon effaced by the continuous action of light upon the chloride of silver. *Niepce* advanced the art of fixing these photographic images; but it remained for *Daguerre* to discover, after many careful and laborious attempts, a method by which almost incredible results are attained.

The substance on which *Daguerre's* photographic images are represented, is a copper plate thinly covered with silver. After being sufficiently purified, this plate is laid over a square porcelain dish, filled with an aqueous solution of *chloride of iodine*, and exposed to the vapour of the iodine, until a goldish yellow, or a violet layer of iodide of silver is formed upon the surface. The plate is now put into the *Camera Obscura*, being carefully kept from the light during its removal, exactly at the place where a well defined image of the object to be delineated appears. After a certain time, the duration of which depends upon various circumstances, the plate is removed from the *Camera Obscura*. There is now no trace of an image to be perceived, this appearing only on bringing the plate over a metallic plate somewhat warmed, and covered with a thin layer of mercury. As soon as the image is sufficiently well defined, the plate is placed in a solution of hypo-sulphate of soda, or in default of this, in a boiling solution of chloride of sodium, by which the coating of iodide of silver is dissolved, and all further action of light prevented.

Light acts on those parts of the iodized plate on which the

light portions of the picture in the *Camera Obscura* have fallen before the action becomes apparent to the eye; thus the portions of the plate which are most exposed to light have acquired the property of condensing the vapour of mercury: here, therefore, the mercury is precipitated in infinitely minute globules, whilst no such precipitate occurs where the light has not acted. After the unchanged iodide of silver has been entirely washed away from the last named parts, we have a fine coating of the precipitate on the light portions, while, where the light does not act, the shining silvered surface appears; and if we hold the plate in such a manner that the mirror reflects to the eye the ray coming from dark objects, this silvered surface forms the dark back-ground, on which the light parts are produced by the light scattered in all directions from the globules of mercury.

If we leave the plate too long in the *Camera Obscura,* the action of the light becomes apparent upon the iodized plate, whilst the iodide of silver is blackened in those parts where the light acts most strongly; the picture thus produced is a *negative picture,* that is to say, the light parts of the object correspond to the dark portions of the image, and *vice-versâ.* If we leave the plate in the *Camera Obscura* until the action of light is visible upon it, it is then too late to procure a Daguerrotype photographic picture.

These pictures can never represent the relations between lights and shadows with perfect accuracy, owing to the different action of the various colours upon the iodized plate; green rays scarcely produce any action, on which account trees always appear very dark; red rays likewise act very slightly. Owing to this circumstance, the Daguerrotype portraits do not produce correct likenesses of the originals.

Talbot has pursued a totally different method in procuring his photographic pictures. He makes use of a paper which is rendered peculiarly susceptible to light by a process which we cannot further describe, and which is termed *Calotype* paper. A negative picture is formed upon this paper in the *Camera Obscura,* and fixed by means of bromide of potassium.

This negative picture is then laid, together with a piece of similarly prepared paper, between two glass plates; the dark portions of the picture keep from the second paper the light which acts through the light parts, and thus a positive picture is formed upon the second paper. Several positive copies may be taken from one and the same negative picture.

SECTION VI.

MAGNETISM AND ELECTRICITY.

PART I.

MAGNETISM.

CHAPTER I.

MUTUAL ACTION OF MAGNETS ON EACH OTHER, AND ON MAGNETIC BODIES.

WE find in the bowels of the earth certain iron ores which possess e property of attracting iron; these are termed *natural magnets.* ıe same property can be imparted temporarily to iron, and per- anently to steel, and magnets formed of this substance, which e termed artificial magnets, are best adapted to the inves- gation of the laws of magnetism from the facility with which a itable form can be applied to them. Artificial magnets are nerally made in the shape of rods, needles, or horse-shoes.

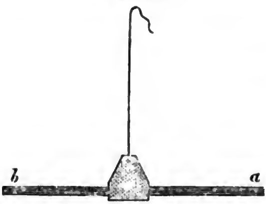
Magnetic poles.—If we dip a magnetic rod into iron filings, we all see on removing it, that the filings will not be equally spended to all parts of the rod, they will fall off immediately from e middle, where the magnetic rod does not appear to exert any fluence; from the middle towards the extremities or *poles,* how- er, this power of attraction increases as may be seen in Fig. 319.

FIG. 319.

One would be led at first sight to suppose that if a magnet were sepa- rated along its neutral line (by a magnetised steel ire, for instance, with which the experiment may be easily made) ither of the divided portions would be true magnets, and that ch would attract at one extremity only; experiment proves the verse however, each part being a perfect magnet having its neutral ne and two poles.

Similar poles repel each other, contrary poles attract each other.—Fig. 320 represents a magnet lying in a casing of paper or metal, and suspended in a horizontal position. If we bring one pole of a magnet near either of the two poles *a* and *b* of another magnet, the pole *a* will be attracted while *b* will be repelled. We term the poles *a* and *b* opposite poles, because they act in different ways upon the same pole if brought near them. If now we invert the magnet which we hold in our hand, in order to bring its opposite pole to the suspended magnet, the reverse will take place, *a* will be repelled and *b* attracted. The two poles of the magnet in the hand are, therefore, also of different natures, and are consequently opposite. In a similar manner we may show that the two poles of every magnet are opposite.

FIG. 320.



If we bring two different magnets to the suspended magnet, it will be easy to find which of the two attracts the pole *a* of the suspended magnet, and repels *b*. If we designate this pole of the first magnet as *n*, and the pole of the second magnet acting similarly as *n'*, *n* and *n'* will be the similar poles of these two magnets. If the second pole of the first magnet be *m*, and that of the other *m'*, the pole *m* as well as *m'* will repel the pole *a* of the suspended magnet, and attract the pole *b*. The two poles *m* and *m'* are likewise similar.

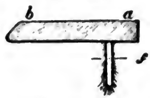
If now we suspend the magnet whose poles are designated *m* and *m'*, in such a manner as to admit of its turning readily in a horizontal plane, and bring the other near it, we shall find that the poles *m* and *m'* will repel each other, as will also the poles *n* and *n'*; similar poles consequently repel each other. While the poles *m* and *n'* and *n* and *m'* being dissimilar poles, attract each other.

There are, therefore, in the two halves into which a magnet is divided by the neutral line, two forces, which, although appearing at first sight to be of similar nature, from their acting similarly upon iron are actually two opposite forces. The neutral line is, consequently, the boundary between two opposite forces, forming the transition from one to the other, and herein lies the reason of their neutral character.

From reasons which we shall presently better understand, one pole of the magnet is termed the *south pole*, and the other the *north pole*.

Under the influence of a magnet, iron itself becomes magnetic.—In order to show this property of iron we must make the experiment represented in Fig. 321. Let an iron cylinder *f* be supported by a magnet *a b*; if we bring iron filings to the lower part of this cylinder, they will continue suspended to it in the form of a little tuft hanging as long as the little cylinder continues to adhere to the magnet; but as soon as the cylinder is removed, the iron filings will fall off, and no further attractive force be perceived. We cannot ascribe this phenomenon to the force of magnets acting at a distance, for if the small cylinder were not of iron we should not observe the phenomenon; of this we shall be still better convinced by observing, 1. that the threads of iron filings diminish gradually from the extremity of the cylinder; 2. that there is a point towards the upper end where the filings do not adhere, consequently, that the small cylinder has a neutral magnetic line; 3. that the filings adhere again above this point, but that they have an opposite direction. The little cylinder is therefore a real magnet, attracting iron filings, having two poles and a neutral magnetic line; the latter, however, does not coincide with the geometrical middle.

FIG. 321.



Instead of bringing iron filings to the suspended cylinder, we may attach to it another cylinder (as in Fig. 322) which will also be supported, to this a third, fourth, and so on; in this way a chain may be formed of which the magnet is the first link. If we remove this link, the whole chain will fall apart, there being no power to hold together the links.

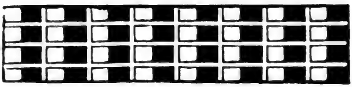
FIG. 322.

Magnetic fluids.—To explain the various phenomena of magnetism, we assume that there are two different magnetic fluids, distributed in the magnet in a manner which we must consider more particularly; the particles of each of these fluids repel each other, but attract those of the other fluid. The magnetic fluids are present in equal quantities in every molecule of iron and steel; but they cannot pass from a magnet to a piece of iron, or from one molecule to another, the magnetic condition depends only upon the manner in which the magnetic fluids are distributed in every individual molecule.

We must suppose a magnet, or a magnetised iron rod (as seen in Fig. 323) to be composed of small particles, each of which

contains both fluids, although in a state of separation; the magnetic fluids being distributed in each particle in such a manner that the similar fluid is turned towards the same side in all the particles. There is, therefore, only one fluid present at the left extremity of the magnet represented in Fig. 323, while the right extremity is solely occupied by the other; the polarity of the magnet is thus explained. We can easily understand from this explanation that a magnet may be broken into two parts, and each separate portion remain a perfect magnet.

FIG. 323.



If, therefore, a piece of iron be magnetised by the influence of a magnet, no magnetic fluid will pass from the magnet to the iron, but the approximation of the magnet will simply occasion a distribution through the iron of the magnetic fluids which have not hitherto been separated in each molecule, and directed towards a definite side, but distributed quite uniformly over the whole.

Iron only retains its magnetic properties so long as the contiguity of a magnet keeps the magnetic fluids separated; on the removal of the magnet the separated fluids again combine, and the iron returns to its natural condition.

A horizontal magnet *a b* supports at one end an iron mass *f*, the weight of which is nearly as great as the magnet is capable of supporting. We now bring another magnet *a′ b′* over *a b* in such a manner that the contrary poles *a* and *b′* are turned towards each other. If we bring the second magnet gradually nearer, in the manner specified, the piece of iron *f* will fall off. The two magnets combined cannot therefore support as much as each one separately. We may easily understand the cause of this; for the second magnet disturbs the actions of the first, whilst it decomposes the fluids of the mass of iron *f* in an opposite sense.

FIG. 324.

Steel resists the magnetising influence of a magnet much better than iron, that is to say, a piece of steel, if it be tolerably large, is not magnetised so strongly or immediately by contact with a magnet as is a piece of iron; and in order perfectly to magnetise a rod of steel, it is necessary that it should be for a longer period in contact with the magnet, or that the latter should be drawn repeatedly over it in the proper manner; when, how-

ever, steel is once magnetised, it does not lose this property very easily, but retains the magnetic character even after the magnet has been removed; we may consequently form permanent magnets of steel, but not of iron.

Perfectly hardened steel admits least easily of being magnetised; but when once it has acquired the magnetic property, it does not readily lose it. When tempered steel loses its hardness by being annealed, it assimilates more nearly to soft iron in its relation to magnetism. Red hot iron is not attracted by a magnet, and a steel magnet entirely loses its magnetic properties on being heated.

Besides iron, nickel and cobalt may also become magnetic.

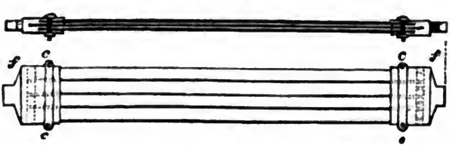
Magnetic armatures.—A magnet may gradually lose its force, owing to various causes. To prevent this, the so called *armatures* are made use of: this term is applied to pieces of soft iron, brought into contact with the magnet in order to preserve its power by means of the magnetic decomposition going on in the soft iron. The following method for thus arming magnetic bars is the best, and will be seen exemplified in Fig. 325. Two like magnetic bars are laid parallel to each other in such a manner that the north pole of the one is directed to the same side as the south pole of the other, to these are attached two pieces of soft iron a b and c d in order to complete the parallelogram. Each of these pieces of iron naturally becomes a magnet of itself, reacting in such a manner upon the magnetic rods $N\,S$ and $N'\,S'$, that the separated fluids are fixed at the corresponding extremities.

FIG. 325.

Magnetic needles and bars lying in the direction of terrestial magnetism may be considered as in some degree armed by the earth.

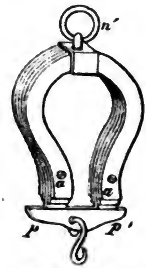
A magnetic battery is a combination of several individual magnets. Fig. 326, represents one constructed according to

FIG. 326.



Coulomb's plan. It consists of 12 separate magnetic bars, forming 3 layers each, composed of 4 bars. The bars of the middle layer

FIG. 327.



are about 2, 5, or 3 inches shorter than those of the other layers, and project about 15 to 18 lines at either side. All the bars are of exactly the same dimensions, and are fastened into pieces of iron *f* serving as armatures. The brass bands *c c'* serve to hold the rods and armatures together. Such large magnetic bundles remain horizontally fixed, when made use of for the purpose of magnetising. The smaller ones employed for friction are constructed on similar principles.

Fig. 327 represents a horse-shoe magnet. It consists of several horse-shoe shaped curved plates of steel, lying immediately on one another, and held together by two screws *a* and *a*, made of iron or brass. Each plate is separately magnetised, before it is used for constructing the apparatus. A ring *n n'* serves to suspend the magnets, and a piece of soft iron *p p'*, the *anchor*, forms the armature. Good horse-shoe magnets are capable of sustaining from 10 to 20 times their own weight.

The armature of natural magnets is represented in Figs. 328 and 329. The parts *l* and *l'* are the *wings* of the armature, and *p p'* the feet. The wings are made nearly as broad as the magnet, and about one line in thickness. The dimensions of the feet depend upon the strength of the magnets.

FIG. 328.

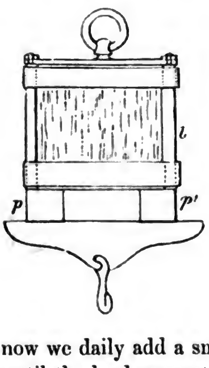
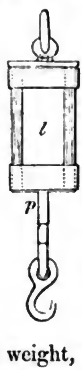


FIG. 329.

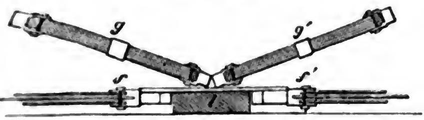


A remarkable phenomenon is observed in natural as well as artificial magnets, which has not as yet been satisfactorily explained, we mean the weakening which occurs on overloading. Let us assume that a magnet can bear 20 kilogrammes. If now we daily add a small weight, we increase its power of bearing until the load amount to 30 or 40 kilogrammes; as soon, however, as the lifter is severed by the application of too large a weight, the strength of the magnet diminishes considerably, scarcely, at last, supporting more than 20 kilogrammes, the weight from which we started. But if we attach a smaller weight, increasing it with

ution, we shall find that after some time the magnet has covered its former strength.

Magnetization of steel needles and bars.—The so-called method separated touch, is managed by placing two strong bundles of agnets, see Fig. 326, in such a manner that the axis of the one incides with the line of prolongation of the axis of the other, and at the opposite poles are inclined towards each other, as seen in ig. 330, where *f* represents the one pole of one bundle, and *f'* the opposite pole of the other. The needle to be magnetised is now laid upon a piece of wood *l*, to which it may be secured to prevent its being displaced. We now take the two touching magnets and *g'*, each in one hand, and holding them at an inclination of bout 25 or 30 degrees towards the horizon, place them in the iddle of the rod to be magnetised, moving them gently and gularly in such a manner that *g g'* simultaneously reach the pposite extremities of the needle, and this process is repeated everal times. It will of course be understood that the touching agnet must touch the needle with the same pole towards which we irect it. This method is especially well adapted to magnetise gularly and perfectly such magnets as are used for compasses, or eel bars which are not more than 4 or 5 millimetres in ickness.

FIG. 330.



The double touch is applied to prepare steel bars which exceed 4 5 millimetres in thickness; in which case, the method above escribed is inadequate to the purpose. The double touch is thus managed. The bar to be magnetised is laid between two bundles of magnets, which are placed over its centre s described in the former method, the magnets must, however, e less inclined, forming only an angle of from 15 to 20 degrees ith the horizon. Besides this, the frictions are not made towards pposite poles, but both magnets are moved towards one extreity of the rod, and then back the whole length. After the agnets have been moved *together* sufficiently long, they are again aised from the middle of the rod. In order to manage this

FIG. 331.

process more conveniently, we may fasten the two rubbing magnets to a kind of triangle of wood or brass; there must, however, at all events, be a space of about 5 or 6 millimetres between the lower parts of the magnets; this is best effected by the insertion of a bit of wood, brass, or lead, as represented in our Fig. at *l*.

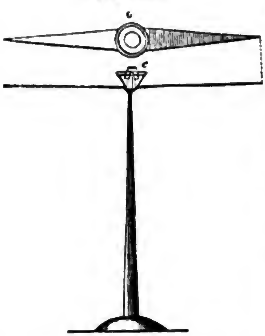
The double touch communicates a very strong degree of magnetism, but it cannot be safely applied to magnetise needles for compasses, or bars intended for nice experiments, since it almost always gives poles of unequal strength, thus occasioning successive stoppages.

CHAPTER II.

OF THE MAGNETIC ACTIONS OF THE EARTH.

Direction of magnets, declination, inclination.—A magnetic rod horizontally suspended by a silk thread, or a magnetic needle revolving easily upon a point in an horizontal plane (this needle is generally made in the form of a rhomboid, as seen in Fig. 332, and has in its centre an agate cap, which reposes upon the steel point forming the pivot) is not in equilibrium in all positions, but takes a definite position, directed towards one definite point of the horizon. It will always return to this position after a series of oscillations if removed from it. The force urging the needle back to this position is magnetic; since no phenomenon of the kind is exhibited in the case of an unmagnetised needle. This remarkable property of magnetism is observed everywhere; in all parts of the world, on all seas, on the loftiest summits of mountains, as in the deepest mines, the magnetic needle assumes a definite direction, to which it will invariably return if removed from it. There must, consequently, be a magnetic force which acts at all points of the earth's surface, for magnetic needles

FIG. 332.



can no more take up a direction of themselves than a body can set itself into motion; in both cases the influence of some foreign force is required. We may prove by means of a simple experiment, that this directing force acts as a magnet, and not as a mass of iron. If we entirely invert the poles of a magnetic needle, they will not be in equilibrium in their new position, but will each describe a complete semicircle in order to return to the state of equilibrium, and reassume their original direction. The directing force consequently distinguishes the two poles, attracting the one, and repelling the other like a magnet, whilst iron will equally attract the poles of a magnet.

When we combine all the different observations that have been made in different places, we are in truth led to regard the earth as one great magnet, whose neutral line is situated in the region of the equator. Hence we have a means offered us of giving fitting terms to the two poles of a magnet.

The two poles of the great terrestrial magnet lie in the vicinity of the poles of the earth's axis, on which account we name the one the *magnetic north pole,* and the other the *magnetic south pole.* These contrary poles attract each other however, and thus a magnetic needle will turn its south pole to the north, and its north pole to the south.

This designation is not, however, universally received, since some designate the poles of a magnetic needle in a totally opposite manner, giving the name of north pole to that pole which turns towards the north.

If we suspend two magnetic needles at the same place at such a distance that they exert no influence on each other, each will assume a direction parallel with that of the other. This parallellism does not, however, prevail for places separated by the distance of several degrees of latitude or longitude from each other. It is of the greatest importance to be able to determine the direction of magnetic needles, that is, to compare them with lines of unvarying position in order to ascertain the variations occurring in the course of time at one and the same place in the direction of the magnetic needle, and the relations existing between the direction of magnetic needles at different places.

The magnetic meridian is the vertical plane, we may suppose, passing through the line of direction of a horizontal magnet, or simply the section of this plane with the earth's surface. The mag-

netic meridian of a place makes with the astronomical meridian an angle, termed the *declination* or deviation. The declination is *east* or *west,* according as the magnetic needle deviates towards one or the other side of the astronomical meridian. In Fig. 333, for instance, *s n* represents the meridian of a place, and *a b* the direction of the horizontal magnetic needle at the same place. The western declination amounted to 18° 37′ 30,55″ at Göttingen in January 1837. We shall presently see that the declination varies with the time. There are places on the earth where the direction of the magnetic needle exactly coincides with the meridian. At these places the declination is of course null, or at 0.

Every apparatus serving to measure declination is termed a *declination compass.*

Fig. 334 represents a compass of simple construction. The

FIG. 333.

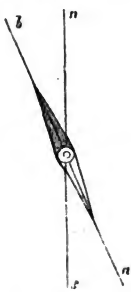
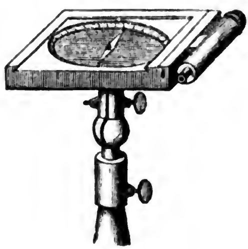


FIG. 334.



point to which the needle is suspended is the centre of a graduated horizontal circle, which may revolve about a vertical axis in its own plane. To the side of the box a telescope is attached, whose axis runs parallel with the line which we may suppose drawn from 0 on the graduated circle through its central point to the line marked 180°. On revolving the horizontal circle in its plane, the extremity of the magnetic needle points towards other lines of the circle. If we place the apparatus in such a manner as to let the needle point to 0 of the scale, the axis of the telescope will be parallel with the needle, coinciding with the magnetic meridian; but in every other position the needle will point to that number of the circle marking the number of degrees of which the angle consists which the direction of the needle makes with the axis of the telescope;

if, therefore, we bring the telescope exactly into the astronomical meridian, we shall see on the graduated circle the angle made by the magnetic with the astronomical meridian.

This instrument serves especially for the measurement of angles, since we can at all times make use of it to determine the angle which the optical axis of the telescope (or rather its horizontal position) makes with the magnetic meridian.

The declination compass generally used at sea, is known by the name of the *Mariner's Compass.*

On the whole, the direction of the magnetic needle inclines more to the north and south than to the east and west, hence it is usual to say that the magnetic needle points to the north.

The magnetic needles we have been considering, are suspended in such a manner as only to revolve in a horizontal plane, that is, about a vertical axis. In the mode of suspension represented in Fig. 320, and also in Fig. 332, the horizontal position is maintained by the centre of gravity of the needle being below the point of suspension. As soon, however, as we suspend a magnetic needle in its centre of gravity, it will not remain equi-poised, but will make with the horizon an angle, which is termed the *inclination.*

The apparatus represented in Fig. 335, is well adapted to show

FIG. 335.

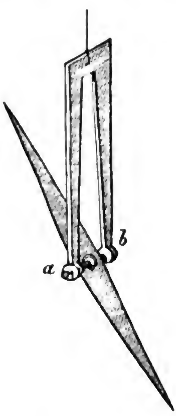
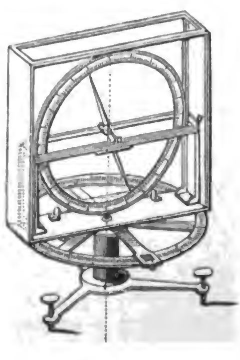


FIG. 336.



the inclination of the magnetic needle. In a brass frame, sus-

pended by a thread, there is a horizontal axis *a b*, which moves very readily, passing through the centre of gravity of the magnetic needle. We see that a magnetic needle thus suspended, can easily move round a vertical or a horizontal axis, and, therefore, that it can freely follow the directing influence of the earth. The needle places itself in such a position, that its line of direction coincides with the magnetic meridian; but the extremity of the needle turned towards the north dips; consequently the line of direction of the needle makes an angle with the horizon, which in our part of the world amounts to about 70°.

If the needle of inclination be applied to a graduated vertical circle, whose planes coincide with the plane of rotation of the needle, as seen in Fig. 336, we may ascertain the amount of inclination on this circle, by making the plane of the vertical circle coincide exactly with the magnetic meridian.

An apparatus serving to measure the amount of inclination, is termed a dipping needle, or a *compass of inclination*.

The inclination generally increases as we approach nearer to the north; in many places the dipping needle assumes an almost vertical position; thus, for instance, in the year 1773 Captain Phipps observed at 79° 44′ north latitude an inclination of 82° 9′, and Parry an inclination of 88° 43′ in latitude 70° 47′. Captain Ross has at last reached the magnetic north pole of the earth. At 70° 5′ N. lat., and 263° 14′ E. long. from Greenwich, he found the inclination or dip to be 90°. The inclination of the magnetic needle is so considerable in high latitudes, that the compass loses much of its practical utility as has been shown in the late North Polar Expedition.

The further we advance towards the south, the more the inclination decreases, and at the equator we come to a point where it is absolutely null, where consequently the needle of inclination is perfectly horizontal; as we advance further to the south we again observe an inclination, but it is in an opposite direction, the extremity of the needle pointing to the south being the one that now dips. This inclination increases likewise with the increase of southern latitude. In the vicinity of the south pole of the earth there is therefore a second point at which the dipping needle stands perfectly vertical, and this is the south magnetic pole.

At whatever degree of geographical longitude we may pass this equatorial zone, we shall always find one point where the needle will be perfectly horizontal. These places where there is no

nation form a curve all round the earth, termed the *magnetic tor*.

he magnetic equator does not coincide with the terrestrial ator, or form any regular circle of the earth's sphere. It ins its greatest southern latitude on the Atlantic Ocean at ut 28° W. of Paris, where it is then about 14° degrees south he terrestrial equator. The two equators approach each other they incline to the west, meeting at 120° W. of Paris; here, ever, instead of turning to the northern hemisphere, it again ines to the south about 160° W. of Paris, in order to reach a ond southern maximum of 3° 75′. At 174° long. it cuts the estrial equator, and remaining within the northern hemisphere, rsects the terrestrial equator again at 18° E. of Paris. The gnetic equator has a N. lat. of 11° 47′ at 62° E. of Paris; ile it is 7° 44′ at 150° E. of Paris, and 8° 57′ at 130° E. of ris. These data will suffice to define, in general terms, the sition of the magnetic equator and the irregularity of its irse.

The total action exerted by the earth upon a magnetic needle, simply *directive, not attractive,* since, if it were the latter, a gnetic needle would necessarily weigh more than before it was gnetised. If we lay a magnetic needle upon a cork swimming water, it will move into the magnetic meridian, without incing any tendency to float towards the north as we might pect.

If we bring a magnet near a floating needle, either attraction repulsion will occur, according to the pole of the magnet arest it; the needle either approaching to, or receding om the magnet. Why does not the needle move towards the rth magnetic pole, if the earth be nothing more than a large agnet? The reason is this: the force of magnetic attraction minishes with the distance, as we shall soon see. If we direct a agnet towards the floating needle, the two poles of the needle ill not be equally distant from the pole of the magnet; consequently the repulsive or the attractive force must preponderate, and forward motion be produced. The north magnetic pole f the earth is, however, so extremely remote from the floating eedle, that the length of the needle does not bear any appreciable roportion to the distance, the one pole of the needle is, therefore, s much attracted as the other is repulsed.

Variations of declination and inclination.—The declination, like

the inclination, is variable; thus, in the year 1580, the declination at Paris was 11^0 $30'$ E., it then diminished, and was null in the year 1663; from this time the declination inclined to the westward, increasing constantly till the year 1814, when it attained its maximum west, amounting to 22^0 $34'$, and again began to decrease.

The inclination of the magnetic needle at Paris has constantly diminished from the year 1671, when it amounted to about 75^0, it being now about $67\frac{1}{2}^0$.

These gradual changes of declination and inclination are called *secular variations;* they are not, however, the only changes to which the direction of the declination is subject.

If we carefully observe the declination needle, we shall find that it continually makes small oscillations, moving alternately from east to west from its position of equilibrium; these oscillations are sometimes regular and periodical, sometimes accidental and abrupt. The former are termed the diurnal variations, the latter perturbations. In general, the north end of the needle continues its onward motion westward from sunrise, and beginning its retrograde motion about 5 P.M.

The *amplitude* of the diurnal variations, that is, the angle between the eastern and western limits, varies; being sometimes only 5 or 6 seconds, and sometimes amounting to ½ minute.

The inclination is likewise subject to similar variations.

The needle of declination makes very strong irregular oscillations, amounting often to more than a degree, on the appearance of an aurora borealis in the heavens.

Earthquakes and volcanic eruptions also appear to act upon the magnetic needle, producing frequently a permanent change in its position.

Intensity of terrestrial magnetism.—If a needle of inclination be drawn out of the magnetic meridian, terrestrial magnetism will endeavour to restore it to its position of equilibrium; it is only on leaving the needle entirely to itself, that it will, after a series of vibrations, resume its position of rest. The period necessary for each one of these vibrations depends upon the mass of the needle, the strength of the magnetism developed, and likewise the force of terrestrial magnetism. Thus the same needle will vibrate with more or less rapidity according to the force of the terrestrial magnetism acting upon it.

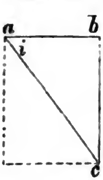
We have thus a method of comparing the force of terrestrial magnetism, as manifested at different places on the earth; it being

only necessary to observe the number of oscillations made in a definite time (as 5 minutes for instance), in different parts of the earth by the same needle of inclination, and by this mode of observation we may easily reckon how the force of terrestrial magnetism stands at one place with regard to that exhibited at another, for the intensities of terrestrial magnetism are as the squares of the number of oscillations made in an equal period of time.

The observations made on the oscillations of a needle of inclination can never yield very accurate results, and therefore the experiments made on the oscillation of horizontal needles or rods are preferable. The force causing the needle of declination to vibrate, is only a portion of a horizontal lateral force, itself but a part of the magnetic terrestrial force acting in the direction of the needle of inclination; if, however, the horizontal intensity and the amount of the inclination be known, we may easily compute the whole intensity.

When the horizontal intensity of the terrestrial magnetism and of the inclination is known, we may easily find the whole intensity by construction.

FIG. 337.



In Fig. 337, $a\ b$ is the horizontal intensity. If now we make the angle i equal to the inclination observed at the same place, and draw a perpendicular from b, $a\ c$ will represent the whole intensity.

If $i = o$, the direction of the terrestrial magnetic force will be in a horizontal plane; this as is well known is the case at the magnetic equator, the horizontal intensity being here equal to the whole intensity. The horizontal portion of the magnetic terrestrial force becomes larger, the nearer we approach the magnetic equator; at the magnetic poles of the earth, where the needle of inclination stands in a vertical position, the horizontal portion of the terrestrial magnetic force is null.

On comparing the results of the observations that have been made on the amount of intensity at different places on the earth's surface, we arrive at the following general result, that the total intensity is smallest in the vicinity of the magnetic equator, increasing the further we move away from it towards the north or south. In the vicinity of the magnetic poles it is about 1,5 times greater than at the equator. The intensity varies also at

the same place, and, like the declination and the inclination, is subject to diurnal variations.

Influence of terrestrial magnetism upon iron.—If we hold a rod of soft iron from 6 to 10 decimetres in length in the direction of the dip, it will become magnetic by the influence of terrestrial magnetism, its lower end becoming a south pole, and its upper end a north pole, as may be easily seen by bringing a small sensitive magnetic needle successively in the vicinity of the ends of the rod. The same pole of the needle is attracted by the one end of the rod, and repelled by the other; by which circumstance we may at once perceive the polar magnetic condition of the rod. On inverting the rod we find its poles have changed, the lower end being again a south pole, and the upper one a north pole.

The same, although somewhat modified action is also produced by terrestrial magnetism on a vertically suspended iron rod, or indeed on any iron rod, let the angle it makes with the direction of the needle of inclination be what it may; the action being, however, less in proportion as it recedes from the direction of the needle of inclination. Terrestrial magnetism exercises more or less strongly the same influence on all masses of iron; all soft iron must therefore assume a polar magnetism under its influence, as may be shown with more or less distinctness, according to circumstances. If a rod of iron be magnetised by the influence of terrestrial magnetism, a few strokes of the hammer will suffice to fix the magnetism, and therefore to convert the rod into a permanent magnet; by striking the iron, a coercive force is consequently imparted to it, which hinders the union of those fluids that have separated in the iron by the influence of the earth. We may thus understand how almost all tools in the workshop of a locksmith become magnets. It appears that chemical changes act similarly to mechanical disturbances in fixing the magnetism imparted by the earth to the iron, for we find that iron rods after being for any length of time in a vertical position, and becoming rusted acquire a permanent magnetism. A certain individual, named Julius Cæsar, a surgeon at Rimini, first observed in the year 1590 that an iron rod on the tower of the Church of St. Augustin had become magnetic from the influence of the earth. At a subsequent period, in the year 1630, Gassendi made a similar observation with regard to the cross on the steeple of the Church of St. John, at Aix, which had been struck down by lightning. It was strongly

sted, and had all the properties of a magnet. Since that time ımerous observations of this kind have been made, and it has en generally found that iron which is somewhat rusted, is ways more or less magnetic.

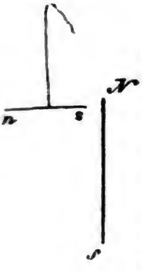
On dipping a horse-shoe magnet into iron filings, the latter will range themselves in a tuft between the poles; if we then moisten em with oil, and expose them to a red heat while they remain ıder the influence of the magnet, a partial oxidation of the iron ll take place, and we shall obtain a tolerably compact mass, the mposition of which is similar to that of natural magnets, and hich also will remain permanently magnetic.

Diminution of magnetic force by distance.—Since we have now ırnt to know the magnetic action of the earth, we may also inves- gate the laws by which the strength of magnetic attractions and pulsions diminish as the distance increases. It will be readily ıderstood that magnetic actions, like all other actions emanating om one point, must stand in inverse relations to the squares distance, that is to say, at 2, 3, or 4 times the distance, the tions will be 4, 9, or 16 times less.

When we endeavour to confirm this law by experiment, we bour under the peculiar difficulty of being unable ever to try the periment on one magnetic pole, without having to contend with e counter influence of the other pole; we must, therefore, ıdeavour to make the distance between the poles so great, as to stroy the disturbing influence exercised by the one over the other.

Let us suppose a magnetic needle so suspended by a thread of ıtwisted silk, as to be able to oscillate freely in a horizontal plane, hile it is sufficiently protected from disturbing currents of air. his needle must be first left to oscillate under the sole influence of rrestrial magnetism. Let n be the number of oscillations observed in a minute, and m the horizontal portion of the magnetic terrestrial force acting upon it.

FIG. 338.



Let now one pole of a highly magnetised steel bar act upon the needle. This steel rod is to be brought into the magnetic meridian of the needle $n\ s$ in a vertical position, so that the pole s of the needle is to be turned towards the pole N of the bar, on which it will act attractively.

The bar $N\ S$ must be so large that the distance $s\ N$ may be as small as possible, in comparison with the distance $s\ S$, so that we may neglect

the action of the pole S on s, without committing any serious error.

If we designate by n' the number of oscillations of the needle for the case, where the pole N of the bar $N S$ acts upon the needle from a definite distance, and call the force accelerating the motion of the oscillating needle f', we shall have, in accordance with the former experiment, $\frac{f'}{f} = \frac{n'^2}{n^2}$.

Supposing the needle, under the sole influence of terrestrial magnetism, to make 15 oscillations in one minute, and 41 when pole N of the bar is removed, 4 inches from the needle, we shall have, $\frac{f'}{f} = \frac{41^2}{15^2}$.

We must now remove the bar to twice as great a distance, so that N is 8 inches from the needle, and then observe the number of oscillations; supposing we find their number in one minute $n''=24$, we shall have, if we designate as f'' the force acting in this case upon the needle, $\frac{f''}{f} = \frac{24^2}{15^2}$.

The amount f' is evidently the sum of the terrestrial magnetic force and the attractive force exercised by the pole N at the distance of 4 inches upon the needle; the latter is, therefore, evidently $f' - f$. In like manner, the attractive force exercised by the rod at a distance of 8 inches upon the needle is $f'' - f$. By the combination of the two latter equations, we shall have the following result: $\frac{f' - f}{f'' - f} = \frac{41^2 - 15^2}{24^2 - 15^2} = \frac{1456}{351} = 4{,}1$.

This experiment shows, therefore, that the attractive force of a magnetic pole acts with nearly four times less intensity when removed to twice the distance.

Weber has indirectly proved the truth of this proposition by his investigations, not merely on the action of a single pole, but on that of the whole magnet at greater distances. He has shown that if a magnetic bar be small in comparison with the distance at which it acts, the total action of the magnet must diminish in an inverse ratio to the third power of the distance, provided the action of a single pole really stand in an inverse relation to the squares of the distance.

In Fig. 339, $a\, b$ is a magnetic bar, 1 decimetre in length, whose centre is 10 decimetres from the point c; the distance of the pole b from c is, therefore, 9,5, and that

FIG. 339.

the other pole $10{,}5^{dm}$. If now c be a magnetic pole, and if e designate as 1 the force with which the poles b and c would tract each other, supposing them to be 1^{dm} from one another, e attractive force will be $\frac{1}{9{,}5^2} = \frac{1}{90{,}25}$, if the attracting ac- on of the pole stand in an inverse relation to the squares of stance. From the same data, the value of the repulsive action the poles b and c is $\frac{1}{10{,}5^2} = \frac{1}{110{,}25}$, the total action exercised the magnet $a\,b$ upon c, is therefore,

$$\frac{1}{90{,}25} - \frac{1}{110{,}25} = \frac{20}{9950}.$$

If now we remove the magnet to double the distance of c, that , if we place it in such a manner that the middle is 20^{dm} from c, e distance $b\,c$ being equal to 19,5, the distance $a\,c$ will be),5^{dm}, and, consequently, the total action of the magnet will e as follows:

$$\frac{1}{19{,}5^2} - \frac{1}{20{,}5^2} = \frac{1}{380{,}25} - \frac{1}{420{,}25} = \frac{40}{159800}.$$

If, therefore, we move the magnetic bar to a distance of $)^{dm}$, instead of 10^{dm} only, its action must diminish in the lation of $\frac{20}{9950}$ to $\frac{40}{159800}$, provided the action of each sepa- ite pole stand in an inverse relation to the squares of distance. ut $\frac{20}{9950} : \frac{40}{159800} = \frac{1}{995} : \frac{2}{15980} = \frac{15980}{1990} = 8$, at double e distance, the total action of the magnet is 8 times weaker, id 8 is the third power of 2.

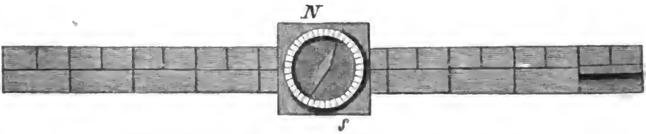
What we have shown here by particular examples, may also be enerally proved, as it admits of a general proof that the total tion of a magnet must be in an inverse ratio to the third power f the distance, if the action of one single pole stand in an inverse lation to the squares of the distance.

We will now adduce an experiment, by which the total action of magnetic bar is shown to be as the third power of the distance, rovided the magnet be small in comparison with this distance.

A bar, 1^m in length, and divided into half decimetres, must be laid that its direction may be at right angles to the magnetic eridian. A small compass is then placed in the middle, as epresented in Fig. 340. The needle of this compass will stand

at 0, if the magnetic terrestrial force be the only one acting upon it. If, however, a magnet be laid sideways upon the rod, the

FIG. 340.



needle will be turned aside; and then this deviating force will be proportional to the tangent of the angle of deviation.

Let us now lay a magnetic bar 1^{dm} in length, in such a manner (as seen in Fig. 340) that its middle may be 45^{cm} from the middle of the compass. In such an experiment the deviation will amount to $11\frac{1}{2}^0$.

If the magnetic bar *n s* be now placed in such a manner that its centre is 30^{cm} from the centre of the compass, the deviation will amount to $35\frac{1}{4}^0$.

The distances here are to each other as 30 to 45, or as 2 to 3; the tangents of the angles of deviation must, therefore, be as 2^3 to 3^3, or as 8 to 27; and here we shall have $\frac{27}{8} = 3{,}375$.

But the tangent of $11\frac{1}{2}^0 = 0{,}2034$, the tangent of $35\frac{1}{4}^0 = 0{,}7115$, and $\frac{0{,}7115}{0{,}2034} = 3{,}49$; the tangent of the angles of deviation are, therefore, very nearly as 8 to 28, or as the third powers of the distances.

PART II.

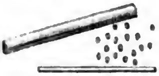
OF ELECTRICITY.

CHAPTER I.

OF ELECTRICAL ACTIONS.

There are bodies which by friction acquire the property of attracting light bodies.—We may easily convince ourselves that bodies in their ordinary condition do not possess the property of attracting light bodies, as gold-leaf, sawdust, paper-cuttings, balls of the pith of the elder, &c.; but if we rub a glass rod, or a piece of sulphur, or sealing-wax, or amber, &c., with a woollen or silk substance, these bodies will immediately acquire this remarkable property. This attractive force is so great, that even at the distance of more than a foot, light bodies are drawn towards the attracting body (Fig. 341). The cause of this phenomenon is called *Electricity*.

FIG. 341.



We may make use of the *electrical pendulum*, (represented in Fig. 342), in order to ascertain whether a body will become electrical by friction. This apparatus consists of a small ball, made of the pith of the elder, and suspended to a fine linen thread. If we would test a body, we bring it towards the ball; if it be not attracted, it is either non-electric, or too slightly electric to produce any effect.

FIG. 342.

By the aid of the electric pendulum, it may be shown that all resins, amber, sulphur, and glass, become strongly electric by friction; the precious stones, wood, and charcoal, seldom give the slightest indications of attraction; metals do not appear, at first sight, to admit of being

made electric, for we do not perceive the least trace of attraction in this apparatus on forcibly rubbing a metal rod. All bodies thus fall under two great classes; that is, such as become electric by friction, and such as do not thus acquire an electric condition. The former we term idioelectric, the latter anelectric bodies.

This division is founded, however, upon an erroneous view, for it has been found that all bodies, even metals, can be made electric by friction, and although we may be unable in many bodies to perceive any trace of electricity from friction, the cause depends upon other circumstances, of which we shall soon treat.

Conductors and non-conductors.—It was formerly supposed that the bodies designated by the term anelectric, could not by any means be brought into an electric condition. In 1727, experiments were made with a glass tube open at both ends on this subject by *Gray*, an English natural philosopher. He wanted to see whether it would become electric if closed up at both ends by a cork stopper. At that epoch science was so little advanced, that experiments were made at random, there being neither hypothesis nor theory by which to conduct the course of investigation. To his great astonishment, Gray found that the stoppers themselves had become electric, although cork belonged to the substances reckoned anelectric. A metal wire passed through the cork became electric, independently of the length at which it was used; having successively carried the electrical rod to the first, second, and third stories of his house, and let the metal wire descend to the ground. He rubbed the glass tube, while a friend brought light bodies to the lower end of the wire, on which they were instantly attracted by it. It follows from thence, that metals have the property of assuming and imparting to other bodies an electric condition. The same property is possessed, however, by all anelectric bodies, and hence they have been termed *conductors* of electricity. Idioelectric bodies, on the other hand, are *non-conductors;* for when, by friction, we make one end of a glass tube electric, the other end exhibits no trace of attraction.

We may easily demonstrate this fundamental truth by the aid of an electrifying machine, of which we may make use to develop electricity, without knowing the principle of its construction. The conductor of the machine is a metallic body, which is made electric. If we bring in contact with the conductor, when in an electrified

ndition, a metal wire suspended by a silk thread, or better still, ne cylindrical metal body standing on a glass pedestal, the tal will be electrified through its whole extent; as soon, howr, as it be connected with the earth by means of any good nductor, all its electricity will instantly disappear.

From this it follows that silk threads and glass rods are nonnductors of electricity *insulators*. A conductor of electricity n, therefore, only remain electric as long as it is *insulated*, that is, rrounded by perfect non-conductors. The air must be an *insu'or*, since, if it were not so, electricity would be instantly withawn by the atmosphere from metals. Water and steam are od conductors, consequently, when the atmosphere is damp the ctricity will soon be lost, which, in a dry condition of the air uld have adhered to an insulated conductor for a long period of ne.

The human body is likewise a good conductor. If we stand on e ground and lay hold of the conductor of an electrifying machine, the electricity evolved from turning the machine will immediately cape, but if we stand upon a bad conductor, as a piece of resin, e whole body will become electric. This explains the reason of metallic rod not becoming electric by friction when we hold it in e hand; all the electricity obtained by the friction being immeately given off to the human body, and thence to the ground.

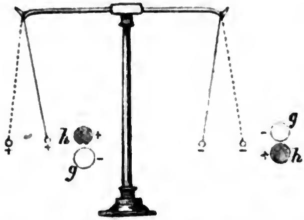
The best insulators may become conductors if they be covered th condensed vapour. It is, therefore, of the greatest importce to the successful result of electrical experiments, that the ass feet, resin rods, &c., used for insulating a conductor, should well dried by warmth and friction.

Instead of dividing bodies into conductors and non-conductors, ought more correctly speaking to term them good and bad nductors, since there do not exist any absolute non-conductors; ell-lac, more especially resin, silk and glass are the worst conctors we have, while, on the contrary, metals constitute the best nductors.

Of the two kinds of electricity.—Let us take a simple electrical ndulum (see Fig. 342), whose nob is suspended to a silk thread. we now bring a rubbed glass or shell-lac rod to the pendulum, e pith ball will be strongly attracted, then touch the rod, and after hering to it for some minutes will be *repelled*. This repulsion pends upon the electricity communicated to the ball by contact ith the rod, for on touching it with the hand, and then bringing it

back to its natural condition it will be again attracted, and repelled after a second time being brought into contact.

FIG. 343.



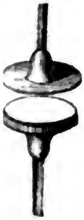
It follows that the repelled ball is really electric from its being attracted by bodies in their natural condition, provided we make choice of conductors for the experiments. If we take two insulated pendulums, one of which has been made electric by contact with a glass rod rubbed with silk, and the other by a rod of shell-lac rubbed with fur or flannel, we shall perceive the following remarkable phenomena. The ball that has been repelled by the glass rod will be attracted by the shell-lac rod, while the one repelled by the shell-lac will be attracted by the glass. The electricity evolved from glass, consequently, is not identical with that evolved from resins, since the one attracts and the other repels.

These two kinds of electricity have received the names of *vitreous* and *resinous electricity*. The former is also termed *positive*, and the latter *negative*. The discovery of these two different kinds of electricity was made by *Dufay* in the year 1773.

Of the electric fluids and the natural condition of bodies.—Owing to the rapidity with which electricity distributes itself through conductors, it has been concluded that it must be a body endowed with remarkable powers of motion, and from the laws of vitreous and resinous electricity, it has been further assumed that there must be two electric, as there are two magnetic, fluids. When these two fluids are united in one body, and when they mutually neutralise each other in that body, the body is in its natural condition. If, however, the two electricities are decomposed in a body, it will become electric, positively, if the vitreous electricity, and negatively, if the resinous electricity predominates. There exists, however, an essential difference between the electric and magnetic fluids; the latter being as it were enclosed in the magnetic particles, while the electric fluid can pass freely from one body to another.

If + electricity be given off by friction in a body, — electricity must be developed in an equal degree. We may show this by a simple experiment. If we rub together two discs of different substances, which are insulated by glass rods, they will exhibit no

FIG. 344.



trace of electricity so long as they rest on each other; as soon, however, as they are separated, the one will be found to be positively electric, and the other negatively so and in an equal degree. This experiment is best exemplified, where one disc is of glass and the other of some wood covered with leather, which has been rubbed over with amalgam. We may also take discs of any other substance, such as resin, metal, &c., covering them with different materials to vary the experiment, for instance, with cloth, silk, paper, &c.

Since a body in its natural condition contains both electricities equal quantities, there is no reason to suppose that it is disposed take up and retain either kind in particular; it may, therefore, ecome positively or negatively electric, according to the substance ith which we rub it. Glass, for instance, becomes positively ectric when rubbed with wool or silk, and negatively so, when ıbbed with cat-skin. In order, therefore, to designate the fluids stinctly, we must thus express ourselves. Positive or + elecicity is that kind of electricity assumed by glass, on the latter ing rubbed with wool or silk; negative or — electricity, on the ntrary, is that kind developed by resins rubbed with cat-skin, wool silk. If we suppose a list of different bodies to be so drawn up, ıat each one when rubbed with all those succeeding it becomes posively a + electric, we shall soon remark how the smallest change of rcumstances alters the order of this series. A change of temperaıre, for instance, may oblige us to move the body upwards or downards in the series. The same action is often produced by making ıe surface of a body rougher or smoother. The colour, the arrangeıent of the molecules or fibres, or simply a more or less strongly pplied pressure may produce similar phenomena. A black silk band, for instance, will be negatively electrified when rubbed ith a white silk riband. Even on rubbing two pieces of the band crosswise together, the one used for rubbing will become ositively electrified, and the other negatively so. Again, on ıbbing a polished glass disc upon a ground glass disc, they will kewise become oppositely electric, &c.

Communication of electricity.—Free electricity may pass from ne body to another, as well by immediate contact as at great istances, the communication depending upon the capacity of he body for conducting electricity and the amount of its urface.

On being brought into contact with an electrified body, bad conductors only take up electricity at the place of contact without its being transmitted over their whole extent. If, on the other hand, we touch an electrified insulator, it will lose its electricity only at the spot touched, the remainder of its surface continuing electric as before. This may be easily seen by means of a rubbed piece of sealing-wax, or a glass rod. The case is very different with good conductors. When touched at one point by an electric body, the electricity will be diffused over the whole conductor, and if we bring an insulated electrified conductor into contact with the earth, it will immediately lose its electricity.

Electricity may also pass from one body to another without immediate contact, and here we remark the extraordinary phenomenon of the *electric spark*. On bringing a metal rod or one of the knuckles near a rubbed glass or shell-lac rod, we see a brightly shining spark emitted, and hear a crackling noise. If the electrified body be an insulated metal of considerable surface, as the conductor of the electrifying machine, the sparks will be more vivid, passing under some circumstances to a distance of 12 inches; their light will then be dazzlingly bright, and the noise accompanying them very loud.

Otto von Guericke, the inventor of the air-pump, was the first who observed electric sparks. Subsequently *Dufay* proved to the astonishment of every one, that they might be drawn from the human body as from the conductor of a machine.

To make this experiment, we must stand upon a piece of resin, or a stool with glass legs (an insulated stool), and bring our body into contact with the conductor of the machine. On turning the machine we shall be concious of a peculiar sensation upon the skin, especially the face, like as if we were entangled in a web. The hair on the head will stand on end. If now the electrified human body be brought into contact with an insulated conductor, as another person for instance, and the latter advance the knuckles, a spark will be emitted, which will be felt in proportion to the distance it has traversed.

Electricity always distributes itself according to the amount of surfaces on passing from one insulated conductor to another; in order therefore to deprive an insulated conductor of all its electricity, we must bring it into contact with another, having an infinitely larger area, as for instance with the ground, for it is thus brought in contact with the whole earth's surface, in which

electricity is wholly lost from being regularly distributed over vast an extent. If we were to bring an insulated elecied metal ball into contact with another equally large, likee insulated and non-electric, the former would lose exactly half electricity. On bringing an insulated metal ball near the iductor of an electrifying machine, only faint sparks will be wn from the machine by means of a non-insulated contor.

A taper that has been just extinguished may be relighted by electric spark. In like manner, ether and alcohol may be luenced by the electric spark; to effect this we must pour the d into a metallic vessel, and bring near to the surface of the d the electrified body from which the sparks are to be itted.

FIG. 345.

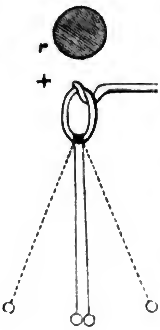
The electric pistol is represented in Fig. 345. It is a small metallic vessel secured by a cork stopper. A metal wire terminating in two small balls *b* and *b'* penetrates into the vessel without being in contact with the wall. For the purpose of effecting this, the wire is fastened with sealing-wax into a glass tube *t t'*, and this cemented into an aperture of the lateral wall. The electric spark conducted by the wire passes from the ball *b'* to to the opposite wall. If now the vessel be filled h an explosive gas, as a mixture of hydrogen and atmospheric , the spark will produce such an effect by the explosion of the chine as to cause the stopper to be propelled with a loud report.

CHAPTER II.

ELECTRICITY BY INDUCTION.

We have seen that each of the electric fluids repels the like id and attracts the opposite. This attraction and repulsion not ly shows itself in the decomposed fluids but on those still in nbination, whence it happens that the combined electricities of body in a natural condition are disturbed by the approxima-

FIG. 346.



tion of an electric body. Let a ring of metal be attached to an insulated hook, and have two metallic threads passing through it, at the end of which are two pith balls. On the approach of an elastic body *r*, the balls will start away from each other even when *r* is very far removed, and no spark is transmitted to them. This divergence increases the nearer we bring *r*.

It is evidently not the effect of transmitted electricity, for the pendulums fall together the moment we remove *r*. The electricities which were combined in the metallic ring and the pendulums before the approximation of *r*, have been separated, that kind of electricity, which is like that of *r*, is repelled towards the balls, whilst the opposite is attracted to the ring. If, therefore, the electric body *r* is a rubbed rod of resin, that is — electric, the ring will become + electric, and the balls —.

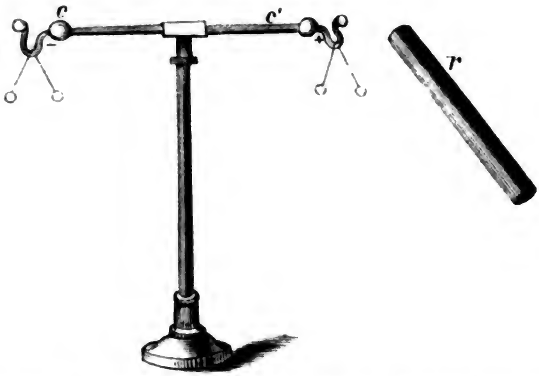
FIG. 347.

We may demonstrate by means of a test disc, that the two kinds of electricity are really distributed in the way indicated. A test disc is made of gold leaf, or gold paper, from 1 to 2 centimetres in diameter, and fastened to a long rod of shell-lac, or thin glass rod covered with varnish. If we touch the ring with this disc whilst the negatively electric body *r* is so near it that the pendulums diverge, the test disc will be charged with the electricity of the ring, the nature of which we shall learn by bringing near the disc a simple electric pendulum, to which electricity has already been imparted. Supposing that the simple pendulum has been made + electric by contact with a glass rod, it will be repelled by the test disc, since the latter, as well as the ring, is + electric.

This experiment may be conducted as follows. We must attach to each hook-like extremity of a metal rod, supported on an insulated glass stand, a couple of pendulums having conducting threads made either of slender metallic wire or linen threads. Both these double pendulums will diverge on the approach of an electric body *r*, the balls of the one pair being charged with +,

the other with — electricity. On removing the body *r*, the

FIG. 348.



ıdulums will again approach each other, because the separated ctricities then immediately combine.

A body electrified by induction acts on its part again by induc- n upon other bodies brought sufficiently near it, that is, within sphere of activity, which may extend to a considerable distance. glance at Figs. 349 to 352 will suffice to show the arrangement

. 349.

FIG. 350.

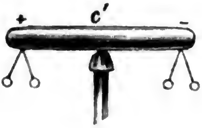


FIG. 351.

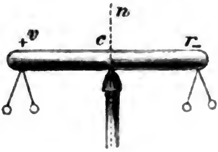
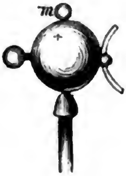


FIG. 352.



at must be made in order to demonstrate the truth of this experiment; *m* is the conductor of an electrifying machine, *c* e insulated metallic cylinder, *c'* another, *b* a metallic ball, and *b'* pith-ball,

If by means of a conducting medium we bring an insulated nductor (electrified by induction) into contact with the ground ıile the electric body still acts inductive by its approximation, the repelled electricity will be carried off by the earth, and e insulated conductor will only remain charged with the elec- icity attracted from the inductive body *r*. If we again destroy

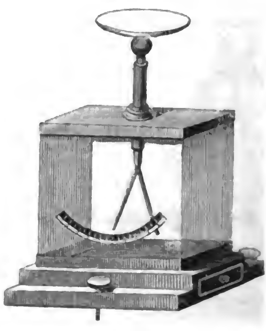
the communication with the earth, and remove *r*, the insulated conductor will be charged throughout its whole extent with the same electricity.

The apparatus in Fig. 346, made in a somewhat different form, serves admirably as an electroscope. Care must be taken that the pendulums are secured in a glass vessel, in order to hinder the injurious interference of external influences, as currents of air, &c., besides which, the conducting system must be carefully insulated. The pendulums may be formed of blades of straw, and balls made of the elder pith, suspended to metallic threads, or of metallic plates.

Fig. 353 represents a gold leaf electrometer. A glass tube passed through the opening of the glass vessel, having a metal rod covered with shell-lac varnish fastened to it, and penetrating into the vessel, while the gold leaf pendulums are fastened to the lower extremity of this metallic rod; a metal plate is screwed on the top.

FIG 353.

FIG. 354.



In order to be able to measure the divergence of the pendulums, a graduated arc is either introduced into the interior of the glass vessel, or instead of this a glass box is used, as represented in Fig. 354, on the side of which the graduated arc is sewed.

The experiment shown in Fig. 346 may also be made by the above delineated electroscope. If we place above it an electric body, as a rubbed glass rod, for instance, the pendulums will diverge; the nature of the electricity collected in the upper plate, may be ascertained by means of the test disc, it being the contrary to that of the approximating body *r*.

If we wish to examine into the nature of the electricity of any body, the electroscope must be charged beforehand with a kind of electricity with which we are acquainted, and this may be done by bringing a body *r*, whose electricity is known, near the apparatus, and touching the plate with the finger. By this means all the repelled electricity is carried off, there remaining only the portion attracted and accumulated upon the plate. It is to a certain extent combined, that is to say, it cannot escape, being attracted by *r*, on which account the pendulums do not diverge; immediately, however, on removing the finger and the body *r*, the pendulums will diverge as the electricity which was combined with the plate by the body *r* disperses itself freely over the whole insulated system, consequently also over the pendulums. The electricity with which the electroscope is in this manner charged must naturally be contrary to that of the body *r*; thus, if we want a negative charge we may make use of a glass rod rubbed with silk, since this is + electric.

FIG. 355.

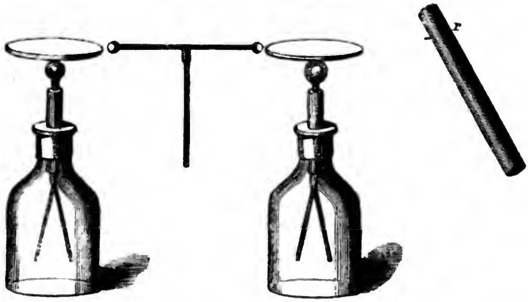
If we bring an electric body to the charged electroscope, the divergence of the pendulums will either be increased or diminished in consequence. It will be increased if the electricity of the body to be examined be the same as that imparted to the apparatus, for by its approximation, the electricities of the electroscope are more thoroughly decomposed than was the case before, and more electricity of the same kind as that already in the pendulums is imparted to them, when their divergence must consequently increase.

If the approximated body be of the contrary electricity to that imparted by the electroscope, the divergence diminishes as the electricity is withdrawn from the pendulum and drawn into the plate. Whatever be the electricity with which the apparatus is charged, there will still be undecomposed electricities in the apparatus which will be decomposed by the approximated body; if the electricity in the latter be contrary to that present in the electroscope, the amount of electricity already developed will be drawn into the plate, while the other will be urged into the pendulums, the divergency of which must therefore diminish. At a definite distance from the approximated body, the electricities will neutralize each other in the

pendulums, which will then fall closely together. If the body to be tested be brought still nearer, the pendulums will again diverge, but with electricity of a kind contrary to that which made them previously diverge.

The divergence of the pendulums likewise diminishes on bring-

FIG. 356. FIG. 357. FIG. 358. FIG. 359.



ing a non-conductor near the charged electroscope. This follows as the necessary consequence of the laws of electric induction.

On uniting two similar electroscopes by an insulated conductor, and bringing an electric body *r* near one of them, the pendulums in both jars will diverge, the one from +, and the other from — electricity. On removing the connecting conductor (we must, of course, hold it by the insulated handle) the pendulums will not meet again, even after the removal of the body *r* effecting the induction, owing to the separated electricities having no way by which they can pass back to each other. We may know that the electricities in both apparatus are of different natures, by bringing the same electric body first to the one, and then the other electroscope, when we shall see them diverge in the one case, and collapse in the other.

The above described phenomena of attraction can also be explained by the laws of electric induction. If a body in a natural condition be brought near one that is electric, its electricities will be decomposed. This will also be the case with the cork ball of the simple electric pendulum. If it be suspended by a silk thread, the repelled electricity cannot escape from the ball, but will be urged to the reverse side of the ball, whilst the attracted electricity will be accumulated in the front. As the attracted electricity is nearer to the body from which the

tion proceeds, the attraction will be stronger than the repulsion; e force urging the ball towards the electric body will be equal to e difference of these two opposite forces; a very small removal of e electric body will, therefore, be followed by attraction. The tion will be far stronger where the ball is suspended to a con- ıcting thread, as in that case the repelled electricity can escape, ıd the attraction will consequently not be weakened.

A ball of shell-lac is not attracted by the approximation of ı electric body, as the approximated body is only capable, with fficulty, of causing induction. This phenomenon resembles hat may be seen in the case of a magnet, which easily occasions magnetic induction in a piece of soft iron, but can only effect ıe same in a piece of steel with extreme difficulty.

The Electrophorus is one of the most important electrical ›paratuses, and may in many cases replace the electrifying ıachine. It consists of a cake of resin, which, as seen in Figs. 56 to 359, is fused in a plate of metal, or a cake of resin simply laid upon a somewhat larger metal plate. It is very important that the surface of the cake of resin should be as smooth as possible. On this cake, the surface of which has been made negatively electric by striking it with a fox-tail or cat's-skin, we place a metal cover provided with an insulated handle *m*. The electricity of the cake of resin acts inductively upon the two electricities hitherto combined in the cover, the + electricity is attracted, the — electricity repelled; he former will, therefore, accumulate in the lower part of the over, and the latter in its upper part. On bringing the knuckle f the finger near the cover, a spark will be elicited, and on ouching the cover with the finger all the — electricity will escape, + electricity alone remaining, which, however, is combined with he — electricity of the cake of resin, as long as the cover is ›n; but if this be removed, the + electricity will be liberated, ınd we may draw a spark of + electricity from the cover.

FIG. 360.

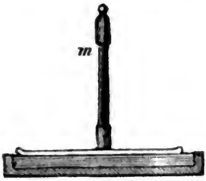


FIG. 361.

If the cake of resin be laid directly upon a metal plate, there is ess fear of the cake cracking by the change of temperature, as nay easily be the case, owing to the unequal expansion of the

metal and resin in melted cakes. The best substance for an electrophorus, is shell lac mixed with Venice turpentine.

Zinc may be used as the material for constructing the metallic plate on which the resin cake is laid. The cover is generally of brass, and has its edge rounded off. Covers of glass, wood, or pasteboard answer the purpose, however, when coated with tin-foil; but care must be taken to have the under surface lying on the cake of resin as smooth as possible. In the place of an insulated glass handle, the cover may be fastened with three silk cords.

The Electrifying Machine consists of a rubbing body, a rubber, and an insulated conductor.

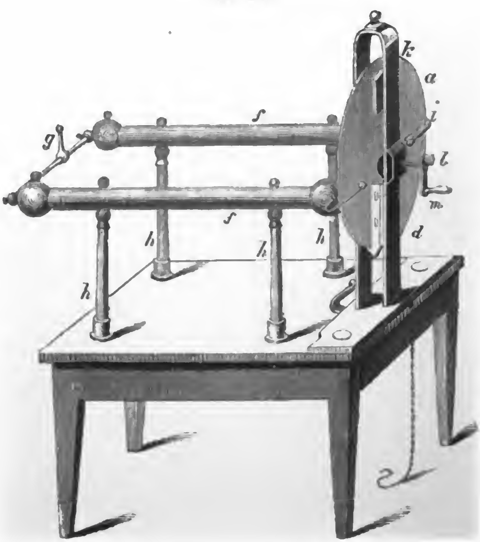
The rubbing body is generally a horse-hair cushion. The rubbing surface, a piece of leather covered with amalgam.

The body rubbed is a glass disc or cylinder.

The insulated conductor is generally a system of hollow conductors made of brass plate, spherically rounded at the extremities, and supported by glass legs varnished with shell lac.

Many different forms have been given to the electrifying machine, the one most in use is represented in Fig. 362. The

FIG. 362.



ımeter of the glass plate *a* varies from 20 to 60 inches. An s passes through an opening in its centre, and supports the ıch *b*. The pillars *d* bear the plate, and likewise the couple of ırs of cushions *e* and *e'*, which rub the plate from the edge to ɔut $\frac{1}{3}$ or $\frac{1}{2}$ of its diameter. The conductor *f g f'* is insulated the columns *h*, and terminates in two arms *i*, which press ınd the plate across its horizontal diameter.

Figs. 363 and 364 exhibit more plainly the arrangement of the shions, and the manner in which they are secured.

FIG. 363.

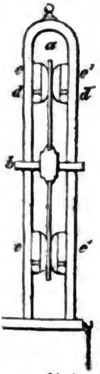
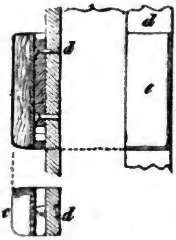


FIG. 364.



If we turn the glass disc round by means of the winch, it will become positively electric by the friction against the leather cushion covered with amalgam. After turning the disc one quarter round, one spot on the disc lying between the cushions always comes to the arms *i*. The + electricity of the glass acts here decomposingly upon the conductor; the — electricity is attracted and flows over the glass, and then brings it back to its former condition, that is, ɜutralising more or less entirely its + electricity. This latter ectricity remains upon the conductor.

In order to prevent the electricity of the glass from being asted in the air, on its passage from the rubber to the arm *i*, ıe disc is protected on both sides by pieces of oil-silk. It is ɛcessary to rub the glass legs and the disc with warm woollen oths, or with heated dry blotting-paper before using the appaıtus, in order that it may work efficiently.

The — electricity of the rubber passes to the ground, and its ıcape is necessary, since if it were to remain upon the cushion it ould acquire such a degree of tension as partially to flow over the lass plate, and partially neutralise the + electricity. The lectricities that are liberated by friction must immediately be ırried off at the spot where they are set free, otherwise we should e unable to develop electricity again at the same place.

Glass cylinders are used as well as the plates in the construction f electrifying machines. Fig. 365 represents a cylinder-machine, 'hich, as usual, is so arranged that positive and negative electricity

FIG. 365.

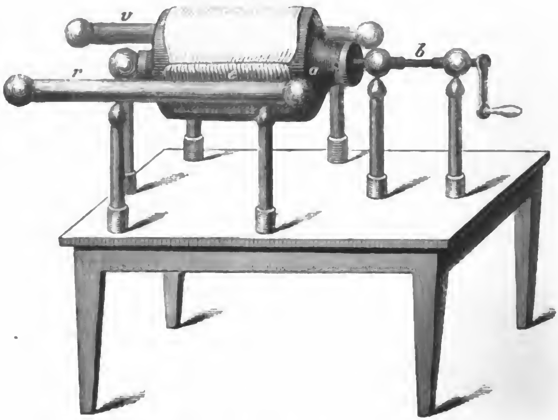
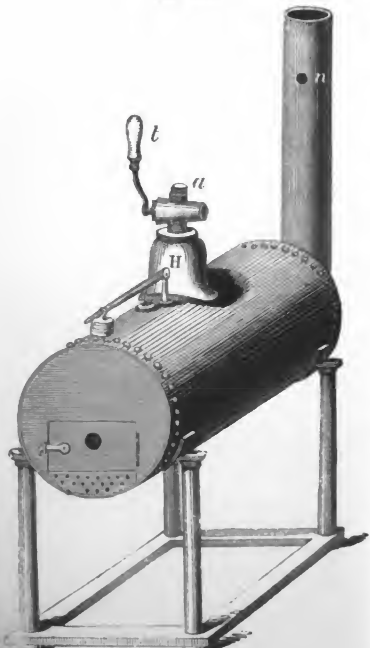


FIG. 366.

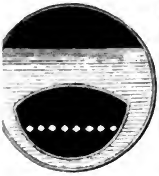


may be engendered at will; *a* is the glass cylinder revolving upon a horizontal axis *b*, and rubbed throughout its whole length by a single cushion *e*. This cushion is connected with a conductor *r*. The conductor *v* is diametrically opposite to the cushion *e*, and is provided with points on the side turned towards the cylinder. The upper half of the cylinder is protected by a piece of oil silk fastened to the rubber *e*, so that the glass rubbed at *e* may not lose its electricity on its passage to the conductor *v*. The latter is of course charged with + electricity. If we wish for a powerful charge

+ electricity on *v*, we must put the conductor *r* in connection th the ground. On the other hand, we must take care to enable e + electricity to pass freely from the conductor *v*, if we want to ive a strong charge of — electricity on the conductor *r*.

The steam electrifying machine.—Many years ago, the discovery as accidentally made in England that a boiler, from which steam as forcibly propelled through a small aperture, was strongly ectric; by pursuing this discovery, means were found for con- rting a steam boiler into an electrifying machine far surpassing its action every known apparatus of the kind. Fig. 366 repre- sents a machine of this description of medium size. The boiler, which is 44 centimetres in diameter, and 96 in length, rests upon four glass legs. It is heated internally in a similar manner as the boilers used in steam-boats. Fig. 367 is a section of the boiler.

FIG. 367.



On the top of the boiler there is a cap, to which a short, brass tube closeable by means of cock is attached; the conducting pipes may be screwed on the hort tube, and will presently be described.

Before the cap there is a safety valve, whose weight is moveble, and may so far project that the steam must exert a ressure of 90lbs. on the square inch, before it can raise the alve.

On the reverse side of the boiler, there is a glass tube connected bove and below with the boiler, so that we may by this tube, see, s in locomotives, the height at which the water stands.

FIG. 368.

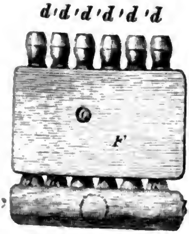


Fig. 368 represents the apparatus with its conducting apertures, delineated as seen from above. The cast iron tube *b c* (Fig. 366), about 24^{cm} in length, and 5^{cm} in diameter, is screwed on at *a*. From this tube the steam escapes through 6 horizontal tubes *d d'*, which pass through a box of brass-plate filled with cold water, by which means a portion of the escaping steam is condensed, and the action considerably increased.

At an opening *o* in the upper cover of the box *F*, a brass tube s put on, which passes at *n* (Fig. 366) into the chimney, and gives a passage to the steam formed in the box *F*.

FIG. 369.

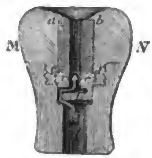


Fig. 369 gives a section of the conducting pipes *d'* represented in Fig. 368, at about half their actual size. At the end of the tube a piece of brass *M N* is screwed on, having a wooden plug *a b c d,* which forms the end of the escape aperture. This longitudinally bored wooden cylinder is secured to its place by a short brass cylinder *r* screwed into the brass work *M N.* A brass plate is so placed before the opening of the bored cylinder *r,* that the steam must pass along the winding course designated by the arrow before it can escape by the opening.

If the apparatus in Fig. 368 be screwed on the boiler, and the steam have the necessary force of tension, the separating cock will be opened by turning the handle *t,* Fig. 366, a quarter round, and the steam escaping with force from the six openings, the boiler will become electric. The escaping steam has the opposite electricity to that contained in the boiler; in order to heighten the action of the apparatus, it is essential to let the steam escape as fast as possible, and this is best effected by placing in the current of steam a row of metallic points fastened to a brass rod communicating with the ground. This rod or staff stands on a glass pedestal, by which it may be insulated, to prove that the steam has really the opposite kind of electricity to that of the boiler.

By means of this hydro-electrifying machine, a battery of 36 square feet in area may be perfectly charged in the space of 30 seconds.

The source of this strong development of electricity is not owing to the formation of gas, as we might at first be inclined to believe, but entirely to the friction against the sides of the tube of the violently escaping steam that is mixed with particles of water. That such is really the case, is proved by the escape of the electricity every moment the safety-valve is opened, although the formation of steam continues in the meantime uninterrupted.

For the generation of electricity, it is essential that the already condensed particles of water should be carried away with the escaping steam through the apertures, an object which is effected by the condensation apparatus *F* seen in Fig. 368. If the escape pipes be of sufficient length, we may dispense with a special cooling apparatus.

Vhen the opening for the steam is formed by a wooden tube lelineated, the boiler will be in a state of — electricity, and the ım in one of + electricity; the same is the case when metal glass is used for the purpose; and if an ivory tube be used, the ler will scarcely manifest a trace of a charge. On applying a le oil of turpentine to the mouth of the tube, the boiler will be itively, and the steam negatively electric.

CHAPTER III.

OF ELECTRIC FORCES.

Diminution of electrical power with the increase of distance.—The by which electrical attractions and repulsions diminish in portion as the distance increases, may be shown by the illations of an electric pendulum. We must let a small shell needle, horizontally suspended by a silk thread, and supporting one end a disc of electrified gold leaf, oscillate by the influence ın electrified insulated ball. If the ball and the disc be charged h the same electricity, the disc will form the end of the electied pendulum turned away from the ball; but if the electricities the disc and the ball be different, the former will be turned ards the latter. We may in like manner judge of the acceleing force exercised on the electric pendulum by its oscillations. om these data it may be seen that electrical attractions and ulsions stand in an inverse relation to the squares of distance.

Distribution of electricity on the surfaces of conducting bodies.— long as a body remains in a natural condition, that is, as long the two electric fluids are not combined, they are probably iformly distributed through the whole mass of the body. As n, however, as one fluid becomes separated from the other, and onductor is charged with free electricity, the individual elements these freed electricities will act repulsively upon each other, reating as far apart as possible until checked by some impenent. A perfectly good conducting body cannot oppose any istance within itself to this dispersion; the electricity, theree, distributes itself over its surface, and would be still further persed if the body were in a space easily penetrated by the eleccity. Electricity always distributes itself over the surface of a

conductor, on which it is retained by the atmosphere, which envelops it as if it were a non-conducting layer.

The following experiment will show in the simplest manner that electricity only distributes itself over the surface, and not through the interior of bodies.

A ball 7 or 8 inches in diameter, and having a hollow 8 or 10 lines in breadth, and 1 inch in depth, must be insulated and charged with electricity; if now we touch this ball in any part with a test disc, it will become charged with electricity, while on touching the bottom of the hollow with the test disc it will not be removed from its natural condition. Let us now consider the manner in which electricity distributes itself over the surface of bodies.

If we electrify an insulated body, the law of symmetry requires that the electricity should distribute itself uniformly over the whole surface, forming everywhere a layer of equal density. We may convince ourselves by experiment that such is the case. If, for instance, we touch the electrified ball at any spot with the test disc, the latter will immediately form as it were an element of the spherical surface, as large a quantity of electricity distributing itself over its surface as there was upon the portion of the sphere covered by the disc; the strength of the electric charge in the disc may be determined after its removal from the sphere by bringing it into contact with the plate of an electroscope. The divergency of the pieces of gold leaf will be the same, at whatever part of the ball we attach the disc.

If the insulated conductor to be electrified be not spherical, no equal distribution of the electricity will take place, that is to say, the electrical layer distributed over the body will not be everywhere equally dense. If by the aid of a test disc, we test the density of the electricity at different parts of a cylinder with rounded ends (Fig. 370), we shall find the density of the electricity greater at the extremities than in the middle. The disc will be much more strongly charged on holding it to the end of the cylinder, in such a manner that its edge shall not touch the top of it, but that its plane shall lie in the line of prolongation of the axis of the cylinder. Similar results are obtained by examining the electrical condition of a disc, for instance, the cover of an electrophorus. We may easily understand that a distribution of electricity must occur

FIG. 370.

the surface of bodies possessing unequal expansion in different ections, for in consequence of the mutual repulsion of the arate particles of the electric fluid, these particles will retire far as possible from the middle of the body, accumulating in remotest projections.

The more a body departs from the spherical form, the less ually is electricity distributed over its surface, and the more es it collect at the points lying most remote from the middle, d that in proportion to the want of density in those parts. It lows, therefore, that if a point be brought near an insulated nductor, the electricity will have an extraordinary density at s pointed end. But the denser the electricity is at any point, the oner will it be able to overcome the resistance of the air, which ives to keep it upon the body. Hence it happens that electricity ws so readily from sharply pointed bodies.

We might adduce a number of experiments by which this wer of pointed bodies is manifested, but we will limit ourselves a few illustrations.

1. On putting a point to the end of the conductor of an elecfying machine, it will be found impossible to charge it in such manner as to draw sparks from it. All the electricity engenred by the turning of the machine being immediately discharged the point.

2. In the same manner, on bringing a point that is in connecon with the ground within a few decimetres of the conductor of e machine, it will be equally impossible to charge the conductor. ne electricity of the latter decomposing the combined electricis of the point, and repelling the like kind, while it will attract the ntrary, and this contrary electricity will accumulate with such rce at the point as to pass over to the conductor and neutralize e electricity of the latter.

On the above mentioned property of pointed bodies rests the nstruction of *lightning conductors*.

Angles and sharp edges to conducting bodies act similarly to oints. It is, therefore essential, carefully to avoid all angular rms in the construction of any apparatus destined to retain elecicity.

On bringing an insulated electric conductor near another conuctor, the distribution of the electricity on the surfaces will xperience considerable modifications. If we bring an electric nsulated sphere near another body of the same kind, likewise

insulated and charged with the same electricity, there will no longer be an uniform distribution of electricity upon the surface. As the electricity of the one sphere repels that of the other, the density of the electricity will be the most inconsiderable at those points of the spheres turned towards each other, and greatest at the most remotely opposite points. Figs. 371 and 372, represent two balls. At *a* and *b* the density of the electricity is at the minimum, at *c* and *d* it is at the maximum. The nearer we bring the two balls, the more will the density diminish at *a* and *b*, and increase at *c* and *a*. If we bring these spheres into contact, the density of the electricity will be null at the point of contact. If the two spheres had been charged with opposite electricities, we should have found the greatest density at *a* and *b*, and the smallest at *c* and *d*. The accumulation of electricity increases at *a* and *b* on bringing the spheres near together, until at last a spark is emitted.

FIG. 371.

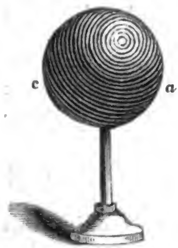
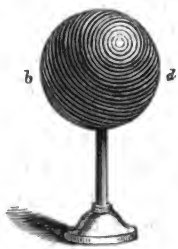


FIG. 372.



A non-electric conductor, on being brought near an electrified insulated conductor, will act similarly to a body charged with the opposite electricity, as it becomes electric by induction or approximation to the conductor.

CHAPTER IV.

OF COMBINED ELECTRICITIES.

We have already seen that if two insulated conductors charged with opposite electricities be separated by a layer of air, the electricity of the one will attract that of the other, in such a manner that we may alternately put either body in connection with the ground without its electricity being entirely carried off. In Figs. 371 and 372 for instance, the ball to the left is charged with +, and that to the right with — electricity, and we alternately touch either

with the finger without the charge being lost. The electricity on the one sphere is attracted by the opposite electricity of the other sphere, and is thus prevented from escaping, being combined. The nearer we bring these two kinds of electricity to each other,

FIG. 373.

the more strongly will they be mutually attracted, and the more perfect will be their combination; if, however, the two conductors be separated only by a layer of air, the combination will not be perfect, as we cannot bring them very near each other without the layer of air being broken, and a spark emitted. To make the combination as perfect as possible, the two conductors charged with opposite electricities must in the place of air be separated by some other insulator capable of opposing a greater resistance to the passage of electricity, and for this purpose glass or resin answers best.

The Franklin plate is especially well adapted to facilitate the examination of the properties of combined electricity. Fig. 373 represents a glass plate, the sides of which are about 1 foot in length. The middle of the glass on either side is covered with tin foil, leaving a free margin all round of about a hand's breadth. We may varnish over the uncovered parts of the glass in order the better to insulate them. If we charge the front part, covered with the tin foil, with +, and the reverse side with — electricity, the opposite electricities will be separated from each other merely by the thickness of the glass disc, this they are, however, unable to penetrate, and thus the combination will be tolerably well effected.

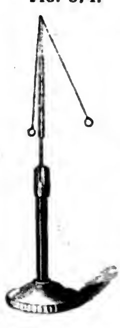
To charge the two-coated sides of the Franklin plate with opposite electricities, it is unnecessary to bring each into connection with the source of electricity. If we bring one side (the front one) into communication with the conductor of the electrifying machine, a portion of the + electricity will pass off from the conductor to the coated surface. The electricity of the front surface acts inductively upon the combined electricities of the back surface; and as soon as we place it in communication with the ground, the + electricity will pass into the ground, while the — electricity will be induced to the reverse surface. But the — electricity of the reverse side acts repulsively upon the + electricity of the front

side, thus enabling electricity to pass again from the conductor to the front coated surface, which again, by its repulsive power, increases the — electricity of the reverse side. We may in this manner easily charge one coated surface with +, and the other with — electricity.

However small the distance separating the two surfaces, the mutual combination is not perfect. In order to have the electricity perfectly combined on the one side, it is necessary that there should be an excess of electricity on the other, that is, that free electricity must be present. On touching the one coated surface of a charged Franklin plate with the finger, while the other side (the front for instance) is no longer in connection with the conductor, we can only bring off a portion of electricity, while a strong charge of — electricity perfectly combined remains upon the reverse surface. In order, however, to have this — electricity perfectly combined, it is indispensably necessary that there should be an excess of + electricity on the opposite side. We may easily convince ourselves that such is the case. If after all the non-combined — electricity of the reverse side has been carried off, we touch the front coated surface a faint spark will be emitted on the approximation of the finger, which proves that free electricity is present. If now we remove all the free + electricity from the front side, there will again be free — electricity on the opposite side, and we may draw a faint spark from the reverse coated surface, &c.

The excess of electricity which must be present on the one surface, in order perfectly to combine the opposite electricity on the other side, may be made apparent to the eye. We must secure with wax a light electric pendulum on each side of the disc in the manner represented in Fig. 374, which shows a diagonal section of the disc. On the side on which there is free electricity, the pendulum will be repelled, while, on the other side it will remain hanging vertically, and in contact with the coated surface. If we touch the pendulum on the one side where there is free electricity, the pendulum will fall while the one on the opposite side will rise. We may, therefore, by alternately touching one or other of the sides make either pendulum rise.

FIG. 374.

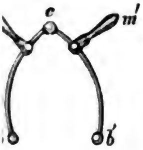


This phenomenon may be easily explained. If there be an excess

+ electricity on the one side, it will act attractively upon the :tricity on the other surface, as well as upon the little electricity the ball of the pendulum. The — electricity certainly repels — electricity in the ball, but the force with which the excess of electricity attracts the negative ball is greater than the force of ulsion. On carrying off the excess of + electricity, the libe- ɜd — electricity distributes itself partially over the ball which is r repelled, there being no excess of + electricity present on the er side to hold it back.

[he apparatus will by degrees become wholly discharged, if we ıtinue alternately to touch the two surfaces with the finger, and ıs remove all the free electricity on the one side. If we ch both surfaces at once, or by any other means put them into ınection with each other, the discharge will take place all at ɜe, while the accumulated opposite electricities of the two surfaces l pass in this manner from one to the other. The *discharging* ' represented in Fig. 375 is commonly used for this purpose.

FIG. 375.

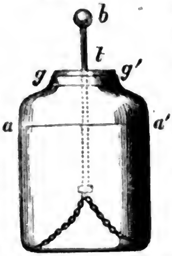


It consists of two curved brass rods $b\ c$ and $b'\ c$, which are united at c by a hinge. Each arm of the discharging rod terminates in a small brass ball b and b', and is also provided with an insulated handle m and m'. We must touch one surface with one of the balls, and on approximating the other to the opposite, a spark of vivid light will be emitted at a certain distance with d explosion.

[he *Leyden jar* is in principle nothing but a modification of

ɜ. 376.

FIG. 377.

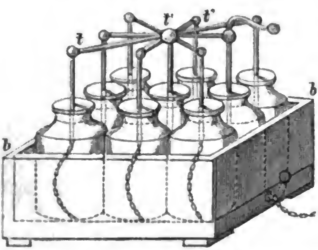


Franklin's plate, and consists of a glass vessel covered externally with tin foil to within a few inches of the rim; internally, the vessel is similarly coated, or filled with some conducting substance, as iron filings or small seed. The inner coating is connected with a brass rod passing through the stopper or cover of the vessel, and ending in a knob. Figs. 376 and 377 repre- ıt two forms of the Leyden jar. The part of the glass that is : covered must be varnished. To charge the jar, the external ıting must be brought into connection with the ground, and the

knob with the conductor of the machine. We may, however, reversely, put the inner coating into connection with the ground, and connect the external one with the conductor of the machine. Leyden jars often discharge themselves, when either a spark is emitted from the external coating to the metal rod, or the glass is broken. In the latter case the jar becomes of course unfit for further use. When we use several conducting bodies to discharge a jar, the electricity will immediately pass over to the best conductor. If we press a metal wire with one hand to the external coating, we may with impunity hold the opposite end of the wire to the knob with the other hand, the electric shock passing through the wire and not the body; to effect this the wire must not, however, be very thin.

In order to obtain a very strong charge, it is necessary to use very large jars, either separate or connected in one *electric battery.* Fig. 378 represents an apparatus of this kind. All the external coatings of the jars are in connection with each other, as well as the inner coatings.

FIG. 378.



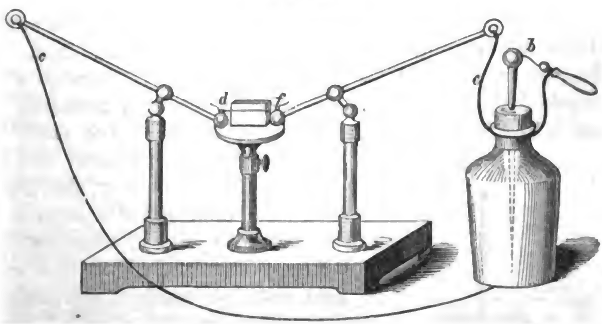
When the electric shock passes from a Leyden jar through the human body, it produces a sensation which it would be difficult to describe, an involuntary convulsion of the nerves. The best manner of trying the experiment upon oneself is to lay one hand upon the external coating, and with the other grasp the knob. In a weak discharge, the shock is only perceptible in the fore part of the arm, if it be stronger, we then feel it in the upper arm, producing an even, sharp pain in the breast, and very strong shocks may prove dangerous. Powerful batteries are not necessary if we want to kill smaller animals, as birds, hares, &c. by an electric shock, the larger batteries are capable of destroying the larger animals. Anatomical examinations of the bodies of the animals killed by an electric shock have shown that there is no injury inflicted on the organs; the violent contortions exhibited, however, in the bodies where the shock has not been sufficiently strong to produce death, manifest the degree to which the nervous system has been affected.

If several persons form a chain by holding each others hands, all will simultaneously feel the shock, on the one first in the ring touching the external coating of the jar, and the last the knob.

We may ignite combustible fluids much more securely by aid of a Leyden jar than by a spark direct from the conductor of the machine. Even pulverised Colophony, scattered over cotton wool, and gunpowder may be ignited by the sparks of a discharge of a Leyden jar.

Henley's general discharging rod represented in Fig. 379 is

FIG. 379.



very convenient in many experiments which may be made with the Leyden jars and the electric battery. The one arm is in connection with the external coating by means of the chain *c*, while to the other arm is secured another chain *c'*, terminating in the insulated ball *b*. If we want the spark to pass through, we must take hold of the insulated handle of the ball *b*, and bring it quickly to the knob of the bottle. The spark will strike at *b* between the two balls *d* and *f*, lying on an insulated plate.

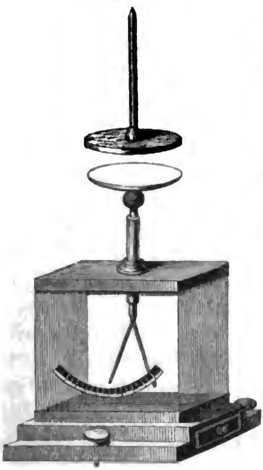
If the balls *d* and *f* be united by a very thin iron wire, the latter will be heated on letting a faint charge pass through it, while a stronger charge will make it red hot, and one still stronger than the former will cause it to fly asunder in separate melted globules, which will be thrown to a great distance.

Bad conductors, that interrupt the course of the discharge, are broken in fragments or filled with holes, if the accumulation of the electricity be sufficiently considerable. A wooden disc, for instance, from 3 to 4 inches in diameter, and from 3 to 5 lines in thickness, is penetrated by the discharge.

The same thing occurs with respect to one or more cards, pasteboard covers, &c. To make this experiment, we must place the bodies we wish to penetrate between the balls of *Henley's* discharging rod, in such a manner that the latter may be in contact with the intervening bodies.

The Condenser.—Properly speaking, every apparatus in which combined electricity is accumulated is a condenser; consequently, the Franklin plate and the Leyden jars may be considered as condensers. The term, however, is generally limited to those apparatus that serve to make electricity, possessing a feeble tension, perceptible by condensation. Condensers consist specially of two conducting plates, separated by a non-conducting medium. Passing by the less perfect instruments of this kind, we will here only speak of the condenser used in combination with the gold leaf electrometer. On this last named instrument, we screw a metal plate as seen in Fig. 380. The plate must be smoothly cut, and covered on its upper surface with a very thin layer of varnish, composed of a solution of shell lac in spirits of wine, put on lightly with a brush while in a very fluid state, on which it will rapidly dry. We now take a second plate similarly prepared and provided with an insulated handle, and place its varnished surface upon the other plate, in such a manner that the metal plates are merely separated by the thin layer of varnish, otherwise fitting together as exactly as possible. This arrangement corresponds perfectly with the Franklin plate, the glass plate being replaced by the thin shell lac layer, and the plates serving as a substitute for the tinfoil coatings, the only difference being, that in this apparatus we may lift off the upper plate at will, while the two coatings in the Franklin plate are immoveable. As the insulating layer is so very thin, and the plates consequently so close together, a perfect combination may be effected. If we bring the lower condensing plate into connection with a weak source of electricity, touching the upper plate with

FIG. 380.



e finger to discharge it, the condenser will be charged in a nilar manner to the Leyden jar, the external coating of which not insulated, while the inner one is in connection with the nductor of the machine.

The whole difference rests in this, that at one time we have a ·ge source of electricity, at another, one of small electric tension ; both cases, however, a condensation of electricity occurs in a nilar way.

When the condenser is charged, the upper plate must be raised ıd that as vertically as possible, so that the contact between the o plates may be destroyed at the same moment at all points), by is the hitherto combined electricity of the under plate will be ·erated, passing down into the gold leaf plates and causing them diverge. When we come to speak of galvanism we shall become quainted with numerous modes of applying the condenser.

CHAPTER V.

ELECTRIC LIGHT AND THE MOTIONS OF ELECTRIFIED BODIES.

The strongest electric discharges that can be accumulated in a dy will never afford the least appearance of light as long as state of electric equilibrium subsists and the electric fluids : at rest. The first requisite for the appearance of electric light therefore, the motion of the fluids and a disturbance of the uilibrium. This condition is always indispensable, but by no ;ans sufficient, it being necessary besides that the tension 'ecting the electric discharge should be adequately great. hilst, for instance, the electricity of a less powerful machine can ss through a metal wire into the ground, without any light ing visible in the dark, we may see the wire of a strongly arged machine surrounded by a luminous brightness. The ısion necessary to produce electric light depends upon the ndition, form and conductibility of the medium through which e electricity must pass. Weak tension will often afford a bright ht, while in other cases the strongest tensions are insufficient to re the least manifestation of light.

Electric light in the air and in other gases under the pressure of

the atmosphere.—The distance at which a spark can be drawn from an electric body, depends upon the conductibility of the substance, the size of the surface and the power of the electric charge. Electricity flows spontaneously from angular bodies and points even under very weak tension, and we may in the dark observe glittering brushes of light, several inches in length. A very strong charge is necessary to make round bodies emit sparks spontaneously; if, however, we bring them near a conductor connected with the earth, sparks will be emitted under some circumstances to a great distance, forming a zigzag line like the course of lightning.

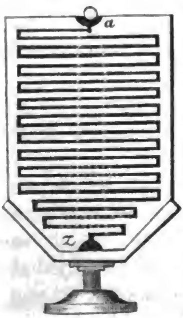
In order to multiply the sparks, it is necessary to interrupt the conductor by which the electricity passes to the earth, and by this means many striking effects will be produced.

We may by means of metal beads (strung upon a silk thread, but separated some millimetres from each other by knots), form cyphers and figures of various kinds, which will continue to shine as long as we turn the machine, from whose conductor electricity passes through this chain into the ground.

Lightning conductors are glass tubes, on which rhomboidal shaped plates, covered with tinfoil, are placed in the order represented in Fig. 381. They are generally laid on in such a manner as to pass round the tube like a progressive screw line. If, while we are holding the one end of such a tube in the hand, we bring the other near the conductor as the machine revolves we shall in the dark see sparks continuously pass between every two plates, so as to appear like one connected line of light upon the tube.

FIG. 381.

FIG. 382.



A lightning plate is represented in Fig. 382. A row of stripes covered with tinfoil are glued upon a glass plate, as shown in the Figure, so that a metallic line of connection goes from *a* to *z*, provided it is not interrupted at the spots marked with small crosses. If we bring *z* into connection with the external coating of a Leyden jar, and then establish a connection between *a* and the knob of the jar, sparks will be evolved at the places where the connecting line is interrupted. We may in this manner represent cyphers and all kinds of figures.

These devices may be altered in a great many different ways; the following examples must, however, suffice.

The brush of light observed in the dark, on placing upon the ıductor of the electrifying machine a point from which the ctricity may flow, is represented in Fig. 383. Negative electricity never gives such divergent and large brushes of light as the positive. This remarkable phenomenon is very deserving of attention, as it appears to afford a characteristic difference by which we may define the two electric fluids.

FIG. 383.

On bringing a metal point near the conductor of a machine with the hand, we observe this brush light.

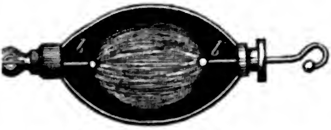
The electric spark of the machine is very bright in conısed atmospheric air, white and intense in carbonic acid gas, . and faint in hydrogen, yellow in steam, and of an apple-green our in ether and alcohol.

The phenomena of light evolved from the electricity of a machine a true, although faint image, of the electric atmospherical :nomena exhibited in thunder-storms.

Electric light in rarefied air.—If a glass tube, several feet in gth, and provided at both extremities with metal caps, be ıausted, and the one end be connected with the conductor of : machine, and the other end with the ground, we shall see a id light within the tube. As the electricity in the rarefied air ets with only a weak resistance, it extends throughout the whole ɔe, marking its passage by flashes of light. If the connection sufficiently maintained, the light will appear fixed and of iform outline, but as soon as a conducting body is brought vards it from without, it will be drawn towards it, and will at : same time become brighter.

We generally take tubes several inches in thickness for these ɔeriments. A somewhat differently formed apparatus is, how-:r, represented in Fig. 384, this being an elliptically-shaped glass vessel. At the two extremities are metal fastenings, one of which has a cock, which may be screwed on to an air-pump. The fastening, or cap, on the other side, is ovided with a leather box, through which passes the metal wire minating in the knob *b′*, which may thus at will be drawn

FIG. 384.



nearer to *b*. When the air has been quite exhausted from the apparatus, the electricity can easily pass, and fill the whole vessel with light. If a little air be suffered to enter through the cock, the light will be less diffuse, forming purplish arcs of light between *b* and *b'*. The more air we admit, the more the expansion of these appearances of light will diminish, approaching more and more to the form of the ordinary electric spark.

FIG. 385.

Electricity likewise exhibits phenomena of light in the *Toricellian vacuum.*

Picard first remarked, on making the mercury oscillate up and down, that a barometer was luminous in the dark, and he was soon convinced that this phenomenon depended upon the electricity developed by the friction of the mercury on the sides of the tube. *Cavendish* constructed the double barometer, Fig. 385, to observe electric light in the Toricellian vacuum; its application will be understood without further explanation.

Motions produced by the discharge of electricity.—As the phenomena of attraction and repulsion have already been described, it only remains for us to make a few remarks upon the motions occasioned by electricity. A metal rod *t t'*, curved at both extremities, in opposite directions, is placed on a conducting point *c p*, Fig. 386, in connection with the conductor of the machine, but in such a manner that it can easily place itself in equilibrium, although at the same time it can just as easily turn in a horizontal plane upon the point. Such an apparatus is termed an *electric fly-wheel.* As soon as the machine is turned, the wheel begins to rotate, and when observed in the dark, the electricity will be seen to flow from the points in the forms of brushes of light.

FIG. 386.

This motion is produced by the discharge of the electric fluid from the points, and corresponds entirely to the phenomena exhibited by the rotation of *Segner's* water-wheel.

Motions occasioned by electrical re-action.—The legs of frogs, when suspended in the vicinity of the conductor of an electrifying machine, do not appear to experience any change; if, by the turn-

FIG. 387.

ing of the machine, the conductor *c* be charged with positive electricity, they will, however, become electric by induction, the attracted — electricity accumulating at *r*, and the repelled + electricity escaping into the ground by the wire *s*. As soon as we draw a spark from the conductor *c*, the sudden re-union of the two electricities will produce contortions in the frog's leg, a proof that on a return to natural condition, the molecules of the bodies are affected by pressure of the electric fluids striving to re-unite. These cts are designated by the term of re-action. The experiment be tried to no purpose on a frog that has already been killed or six hours, but it will succeed very well with one immediately r it has been killed, or better still with the living animal.

n the vicinity of a powerful machine, even a man will eive similar shocks when standing in communication with the und. The discharges of thunder-clouds act in like manner, t is, by a direct shock, and by re-action.

PART III.

GALVANISM.

CHAPTER I.

ELECTRICITY OF CONTACT, AND ON THE GALVANIC CIRCUIT.

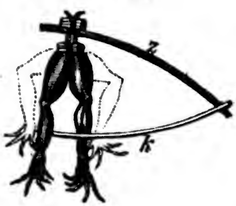
In the year 1789, *Galvani* made a discovery at Bologna, by ich a new field was opened to Physics. This discovery was the servation of the seemingly unimportant fact, that the freshly epared limbs of frogs, suspended by copper hooks to an iron l, were convulsed as often as the muscles of the thigh were ought into contact with the iron-railing by the wind, or any other use. The copper hook was in contact with the crural nerve.

It was at first supposed that this phenomenon could be explained the existence of a kind of nervous fluid, similar to the electric

fluid; the organic body was regarded as a kind of Leyden jar with respect to this fluid, the nerves serving as the coating on the one part, and the muscles on the other. A discharge ought to take place as soon as the nerves and muscles were brought in connecting communication with each other, as seen in the experiments of *Galvani*, with the copper hooks and iron-railings.

Alexander Volta repeated with unwearied attention the experiments of *Galvani*, and soon found that a circumstance had hitherto been wholly overlooked in the experiment, which was very essential to its success. For instance, to obtain a strong effect it was indispensable that the circuit of connection between the nerves and muscles should consist of two different metals in contact with each other. He made the experiment, as represented in Fig. 388. One part *z* of the connection is zinc, the other *k* copper. Both metals must have a perfect metallic surface at the place where they come into contact with each other, and where they touch the limb of the frog. *Volta* concluded from his experiments, that the leg of the frog was not to be regarded as a Leyden jar; that the fluid acting here was not developed either in the nerves or muscles, but by the contact of the two metals, and that it was perfectly identical with the common electric fluid. These views were contested by Galvani and his adherents, each party seeking to confirm the correctness of his theory by new experiments, until at length Volta's opinions were generally received and adopted.

FIG. 388.



Direct proofs of the development of electricity by contact.—The idea that electricity could be developed by the mere contact of heterogeneous bodies only gained credit by degrees, the severity of science requiring direct and convincing proofs; these were, however, soon afforded by Volta, by the aid of an apparatus invented by him some years previously, viz., the conductor with which we have already become acquainted. The experiment he made is conducted in the following manner. After having ascertained that the condenser screwed to the gold-leaf electromotor, Fig. 389, will hold a charge well, and after restoring it to its natural state, we place with the other finger the upper plate in connection with the ground, while the other plate is touched by a piece of zinc, also in connection with the ground, by being held in

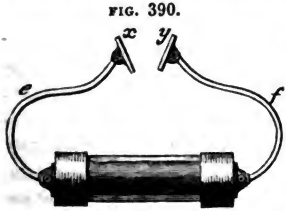
the other hand. It follows, of course, that the surfaces of the plates of the condenser must not be varnished where they are not in contact with each other, otherwise there could be no metallic contact between the zinc and the brass (which is almost the same in this case as pure copper) of one of the plates of the condenser. If we now withdraw the finger from the upper, and the zinc from the lower plate, after the contact has lasted for a minute or so, and then lift off the upper plate of the condenser, we shall perceive a decided divergence of the gold leaves. Whence comes this electricity? It can evidently arise only from the contact of the zinc and copper of the lower plate of the condenser; here there is an especial force at work, to separate the fluids and put them into motion; the positive electricity will pass to the zinc, and from thence into the ground, while the negative, on the contrary, will be driven to the lower brass, or copper plate, and combined there, while it acts decomposingly upon the upper plate. If now the latter be raised up, the combined — electricity in the lower plate can diffuse itself, and thus effect the divergence of the gold leaf.

FIG. 389.

If we vary the experiment by touching the upper plate of the condenser with the zinc, and the lower with the finger, the gold leaf will diverge with + electricity.

The development of electricity by the contact of different metals may be still better shown by help of *Bohnenberger's electroscope*. The accompanying Fig. 390 represents according to *Fechner's* views, the best form for this instrument.

FIG. 390.

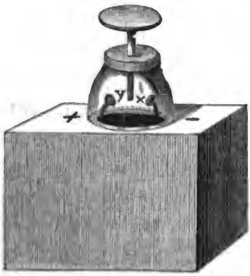


In a horizontal glass tube there is inserted a so-called *dry* or *Zamboni's* pile, the properties of which we shall consider at a subsequent period, the glass tube is closed at its extremities by metal caps, from which pass metal wires *e* and *f*, terminating in the plates x and y. *Zamboni's* pile has this property, that one end is always positively, and the other negatively electric, consequently one plate x, for example,

will always be charged with —, and the other with + electricity.

A *Zamboni's* pile of this kind is fixed in a wooden box, Fig. 391, in the upper part of which there is an aperture for the passage of the poles x and y.

FIG. 391.



If now we suppose a piece of gold leaf suspended midway between these poles it will remain at rest, being equally strongly attracted by both poles; on charging it slightly with positive electricity, it will, however, draw nearer the negative pole, and, *vice versa,* it will approach the positive pole on being charged negatively.

A strip of gold leaf is suspended between the two poles; and being fastened to a metal rod inserted in a glass tube is insulated in the same manner as the rod to which hang the pendulums represented in Fig. 389; here also the gold is within the glass vessel to prevent the disturbing action of currents of air.

We may screw metal plates to the upper end of the metal stem holding the gold leaf. Let us assume that a perfectly smooth copper plate of good metallic surface has been screwed on; on placing upon this copper plate a similar zinc plate with an equally good metallic surface, a discharge will follow as soon as we lift off the zinc plate, showing that the copper plate was negatively electric.

If the zinc plate had been screwed on the instrument, a discharge towards the negative pole would have followed the removal of the copper-plate, because the zinc had become positively electrified by contact with the copper.

This experiment shows then not only that electricity is developed by the contact of copper and zinc, (copper becoming negatively, and the zinc positively electric), but also, that the largest amount of developed electricity remains combined at the surfaces of contact between the two metals, and that a proportionately small part is freely distributed over the metal plates, since the discharge does not follow till after the raising of the other plate.

Such an excitement of electricity occurs almost universally when

heterogeneous substances come into contact with each other, it furnishes, however, some of its most striking illustrations with the metals. The unknown cause of the development of electricity by the contact of heterogeneous substances is termed the *electromotor power.*

Scale of Tension.—The electric tensions developed by the electromotor force, and distributed over the bodies in contact, is not equal for all substances. Metals are good *electromotors,* but even among them we observe a great difference in this respect. For instance, zinc will become much more strongly charged with + electricity when in contact with platinum than with copper; copper will become negatively electric when brought into contact with zinc, and positively so when in connection with platinum. The following table exhibits a series of bodies so arranged, that each preceding one becomes positively electric when in contact with all the succeeding ones.

+
Zinc
Lead
Tin
Iron
Copper
Silver
Gold
Platinum
Charcoal.
—

The electric difference between zinc and copper, and that between copper and platinum, are together equal to the electric difference between zinc and platinum, that is, if we lay a copper plate upon a zinc plate, and a platinum plate on the former, the electric tension of the extreme plates will be precisely as great as if the platinum and zinc plates lay immediately over each other. All bodies in the above given series bear the same relation to each other, for if we place three layers together, the electric tension of the extreme plates will always be the same as if they were in immediate contact, and there were no intervening plates.

The same holds good with respect to 4, 5, or more metal plates ranged the one above the other, the tension of the extreme plate will be the same as if there were no intervening plates. All metals assume a decided position in this scale of tension; charcoal being in this respect entirely similar to a metal, and more electro-

negative than platinum. Many compound bodies also assume a definite place in this scale, as for instance, binoxide of manganese, oxide of iron, sulphuret of iron, sulphuret of lead, &c.; but other compound bodies, as fluids, do not obey the laws of such a scale of tension.

Zinc will become negatively electric in contact with pure water, but now if we put water into this scale of tension, we must, from its relation to this metal, place it over zinc. If water really took this position, platinum would become much more strongly negative than zinc in contact with water. Experience, however, shows the contrary to be the case, platinum becoming actually much less negatively excited than zinc; we see, therefore, that water is a body that does not obey the laws of this scale of tension. Diluted sulphuric acid exhibits a similar relation, exciting zinc and copper negatively, the former, however, much more strongly than the latter body; platinum and gold are positively excited by diluted sulphuric acid.

The peculiar property of many fluids, which prevents us from ranking them in the scale of tension, enables us to produce a stronger electric tension in moist conductors by layers of metal plates, than can be excited by two metal plates in contact with one another; we shall see this more plainly exemplified in the *voltaic pile,* which we are about to consider.

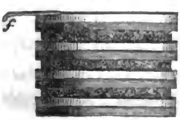
Construction of the voltaic pile.—Three different bodies are used in the construction of the voltaic pile: viz. two metals, and a third body having no place in the scale of tension.

The metals generally used are copper and zinc, two bodies remotely separated in the scale of tension; zinc forms the positive and copper the negative element. A copper and a zinc plate are usually soldered together.

The third element of the voltaic pile is a moist disc, that is a piece of cloth or pasteboard saturated with pure water, a very dilute acid or a solution of salt.

Let a copper plate which is a negative element, be placed in connection with the ground by means of a copper wire *f*, Fig. 392, an equally large zinc plates being laid upon its upper surface. By the electromotor force, the zinc will become positively, and the copper negatively electrified; but the liberated electricity will pass off into the ground, whilst there will remain upon the zinc plate liberated electricity, he density of which will depend upon the electric difference

FIG. 392.



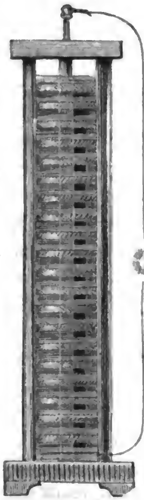
between copper and zinc. If we assume this density as a unity, we may say that under these circumstances the density of the liberated electricity upon the copper is 0, while liberated + electricity of the density 1 distributes itself over the zinc. If now by any means a portion of the liberated electricity were withdrawn from the zinc, so that its density became less than 1, the loss + electricity experienced by the zinc plate would be immediately compensated for by the electromotor force, while an amount of — electricity, fully equal to the newly developed + electricity passing to the zinc plate, would be communicated to the copper plate, and thence to the ground. We must now lay a piece of moist cloth upon the zinc. Let us then assume for the sake of simplifying the matter, that this exercises no electromotor force when in contact with zinc, acting merely as a conductor, then a portion of liberated + electricity will pass from the zinc to the moist cloth, the loss being, however, immediately supplied, so that the density of the liberated + electricity on the zinc will remain at 1, while the liberated + electricity of the density 1 will likewise distribute itself over the damp cloth. If then a copper plate be again laid on the moist piece of cloth, + electricity will then distribute itself over it, and attain a density 1. We shall now have, therefore, on the under copper plate a density of 0, and + electricity of a density = 1 on the zinc plate, the moist cloth and the upper copper plate.

If we lay a zinc plate upon the upper copper plate, the former will be charged with free + electricity of the density 1, even if there be no electromotor force at work; the electric difference between copper and zinc will, however, remain still the same, being according to our previous showing always = 1; if, therefore, the upper copper plate have + electricity of the density 1, the density of the + electricity on the superposed zinc plate must be = 2.

In the same manner, we may further conclude, that on laying upon the second zinc and copper layer another moist cloth, and then again a copper and zinc plate in the same order, the copper being above the zinc plates, the density of the liberated + electricity on this third layer will be = 3. If we continue to pile the elements in the same order, namely copper, zinc and moist pieces of cloth, the freed + electricity upon the 4th, 5th ... 100th zinc plate will have a density = 4, 5 ... or 100.

The above described arrangement is called the *voltaic pile* from the name of its inventor, and is represented in Fig. 393, as consist-

FIG. 393.



ing of 20 pairs of plates. The stand is made of dried wood, the pillars supporting the pile, of glass.

The one end of the pile is called the *zinc end,* from the plate terminating the series, or also the *positive pole,* and the other is the *copper* or *negative pole.* In the previously described arrangement, the negative pole was in connection with the ground, the positive one insulated, while + electricity was distributed over the whole pile, the density increasing from below upwards according to our considerations. If the negative pole be insulated and the positive one put into connection with the ground, the density of the liberated electricity upon the zinc end will be 0, whilst — electricity will be distributed over the whole pile, its density increasing towards the copper end.

The insulated pile.—Let us assume that we have one pile consisting of 100 double plates, whose negative pole is in connection with the ground, and another precisely similar to the former, with the exception of its positive pole communicating with the ground. If now we put the two piles together in such a manner that by the interposition of a piece of wetted cloth, the two discharging poles may touch each other (that is the + pole of the one pile and the — pole of the other) we shall have a single pile of 200 double plates, the halves of which will be still in the same condition as before; even on interrupting the conducting communication with the ground. The middle will be consequently in its natural condition even when the connexion with the earth has ceased. The one half will be positively, and the other half negatively charged, the strength of the charge increasing from the middle towards the poles. The electric tension at each pole will be precisely the same as at the insulated pole of a pile of 100 double plates, where the opposite pole has been connected with the ground. If we disturb this equilibrium by taking away a portion of electricity from one pole, the tension will be diminished here, while it will increase at the opposite pole, and the point of the pile still in a natural condition will be moved more and more from the middle towards the pole from which electricity has been withdrawn. If, however, the whole pile remains insulated, the former condition will be gradually

restored, that is to say, the condition of equilibrium gradually return to the middle, because there will be constantly a larger discharge of electricity passing from the more strongly charged pole. Electric equilibrium is, therefore, restored in each thoroughly insulated pile in such a manner that the middle is in a natural condition, while the two halves are charged with opposite electricity, the density of which increases from one pair of plates to the other towards the poles.

The closed pile.—As the two poles of an insulated pile are always sources of opposite electricity, it is clear, that if we join to each pole a wire, each of these wires will become charged with the electricity of its pole. We thus procure a positively and a negatively charged conductor, if the two conductors be brought into contact with each other, a *constant* re-union of the electricities developed in the pile must take place. This is shown in Fig. 393. On bringing the two wires (often called the two poles) within a short distance of each other, we see an uninterrupted current of sparks pass from the one to the other.

If we bring the two conducting wires into immediate contact with each other, that is, if we close the circuit, the passage of sparks will cease, although all electrical action will not be wholly destroyed on that account. Electricity is continuously developed in the pile, and a reunion of the electricities separated in the pile is continuously taking place at all points of the closing wire. While everything, therefore, appears at rest externally, there is internally continual activity and motion.

This electric current is capable of producing very powerful effects upon the nerves, of making metal wires red hot, the magnetic needle deviate, and of occasioning chemical decompositions. We shall soon proceed to the consideration of some of these actions.

The dry pile.—In dry piles, the electromotors are likewise metallic substances; but the conducting medium separating every two pairs is not a fluid, but some solid body, which is either perfectly dry, or only partially damp. Among the different apparatus of this kind that have successively been suggested, that of *Zamboni* appears the most efficacious. On a piece of common writing paper, exactly as moist as it would be if left to itself in damp weather, we fix with gum or starch, on one side silver leaf (zinc), while we rub finely pulverised manganese (binoxide of manganese) on the other with a cork; several sheets of

paper thus prepared are then laid over one another, and cut with a stamp into round pieces from 10 to 15 lines in diameter. Piles of from 1000 to 2000 double plates are now made from these round discs, which must, however, be carefully piled up in the same order, so that the zinc sides are all turned either upwards or downwards. The pile must be compressed in order to secure a perfect connection between the metal plates, after sufficiently strong metal plates having 3 or 4 projecting parts have been attached to the extremities, and joined together with silk cords. The pile is rubbed over with melted sulphur or shell-lac to protect it from the influence of the weather.

We may also form these dry piles from gold and silver paper. For this purpose we glue together on the paper sides a sheet of fictitious gold leaf (copper), and a sheet of fictitious silver leaf (tin), so that we obtain a piece of paper covered on the one side with copper, and on the other with tin. From the paper thus prepared the discs are cut.

Properties of the dry pile.—A *Zamboni's* pile of 2000 plates is unable to give the least shock, or produce the least chemical decomposition, notwithstanding that its poles show a marked tension. Even a pile of 100 or 200 double plates produces divergence in a gold leaf electromotor without the use of a condenser; and to effect this, it is only necessary to hold one pole in one hand, while we touch with the other hand the plate or the ball of the electromotor. We obtain a very considerable divergence with piles of from 800 to 1000 double plates.

If we touch one coating of a Franklin plate with the pole of such a pile whilst the other pole is connected with the ground, we may often succeed in imparting so strong a charge to the plate as to cause the emission of a spark by its discharge.

If both poles of the pile be insulated, the opposite electricities will soon accumulate in equal proportions at the poles; the tension increasing here until the quantity of electricity lost by each pole in a given time through the action of the atmosphere is equal to the quantity again imparted in the same space of time to the pole by the pile. From this moment the tension at the poles remains constant. If now the air be more moist, the electric loss at the poles will amount to a larger fraction of the electricity accumulated there, whilst the amount of electricity conveyed to the pole will remain the same; hence it follows that the tension at the poles must be less in damp air than in a dry state of the atmosphere.

If we arrange two *Zamboni's* piles side by side, in such a manner that the positive pole of the one, and the negative pole of the other is directed upwards, a light pendulum must constantly oscillate between the two poles. On this principle is grounded the so-called *perpetual motion.*

A piece of gold leaf suspended between two *Zamboni's* piles, will incline first towards one and then towards the other pole, provided it be but feebly charged with either kind of electricity. Instead of the two vertical piles we may make use of a horizontal one, whose poles are connected by means of conducting wires with two metal plates standing opposite to each other, and thus we shall obtain the apparatus described at pages 361 and 362.

Different forms of the galvanic circuit.—All apparatus serving to produce a continual electric current are termed galvanic circuits, They are generally constructed of two metals and one fluid. The voltaic pile formerly described was the first apparatus of the kind; the form offers however many objections. The lower layers, for instance, are more strongly compressed by the weight of the upper layers, the damp discs are thus dried while the fluid escapes at the side of the pile; by which means a conducting communication is established between the separate pairs of plates highly injurious to the combined effect of the whole.

The *Trough apparatus,* which was in use for a longer period is represented at Figs. 394 and 395. The separate elements consist of rectangular plates of copper and zinc soldered together. They are laid in parallel rows in a wooden case b b', whose inner walls are covered with a non-conducting coat of resin; the pairs of plates being so inserted that the intervals between every two form cells or troughs, which are filled with acidulated water. This layer of water, about 3 lines in thickness, supplies the place of the moist pieces of cloth.

FIG. 394.

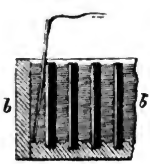
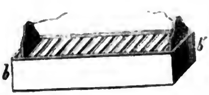


FIG. 395.



In other galvanic apparatus the fluid is put into separate vessels or glasses ranged circularly or in a straight line. Each glass contains one zinc and one copper-plate not in contact with each other, while every zinc plate is connected with the copper-

plate of the preceding glass by a copper wire or copper band. To this class belongs especially *Wollaston's battery*. To understand the construction of this apparatus, we must first consider two double plates, of which a side view is represented in Fig. 396, and a front one in Fig. 397. The copper band *c s* is soldered

FIG. 396.

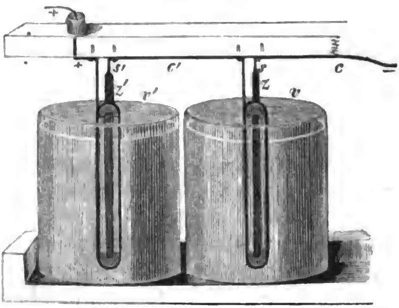
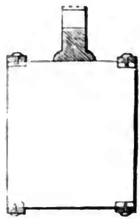


FIG. 397.



to the zinc plate *s z* at *s*; *c' s'* is the second band of copper soldered at *s'* to a second zinc plate. The copper band *c' s'* is connected with a copper-plate, which is entirely curved round the first zinc plate without touching it.

A similar copper plate passes round the second zinc plate, being connected with the wire of the negative pole. Each pair of plates is immersed in a vessel filled with acidulated water. The first zinc plate becomes + electric when brought into contact with the band of copper *c s*; this + charge passes through the fluid to the copper plate which surrounds the zinc plate without touching it, and from this copper plate through the band of copper to the second zinc plate, &c. This arrangement has great advantages:— 1. A copper surface is opposed to the two surfaces of each zinc plate; 2. The stratum of intervenous liquid through which the electricity passes from a zinc plate to the next copper plate, is extremely thin; and 3. From the considerable quantity of liquid in each vessel, its nature is not so rapidly altered, as is the case with the dry apparatus, whose activity soon diminishes. Fig. 398 gives a side, Fig. 399 a front view of a complete *Wollaston's* battery, and Fig. 400 the ground work. The whole number of pairs of plates is fixed to a wooden frame, so that they may all be dipped simultaneously into, or taken out of the

quid. Water is the liquid generally used, to which $\frac{1}{10}$th ılphuric acid, and $\frac{1}{20}$th nitric acid, is added. The number of airs of plates, and their surface required, depend upon the urposes to which the voltaic apparatus is applied. Many henomena may be produced with a battery of many pairs of nall size, others, again, require a single pair only, but of conderable dimensions, and with perfect metallic contact.

FIG. 398.

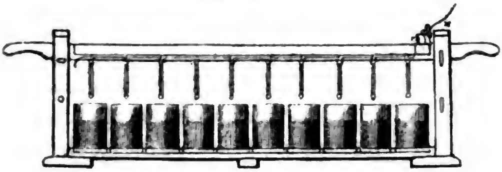


FIG. 399.

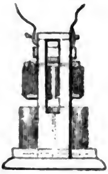
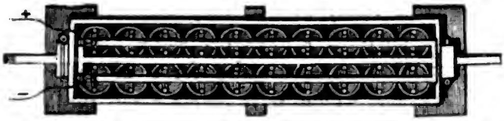
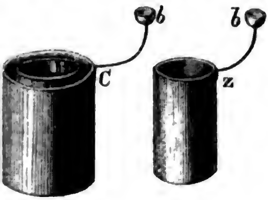


FIG. 400.



The simple circuit shown in Figs. 401 and 402, is used for such xperiments as require a large quantity of electricity in motion, but of a small degree of tension. *C* is a vessel formed of two cylinders of copper sheeting of different diameters, the one placed within the other, and so arranged that the space intervening between the two may be filled by the zinc cylinder *z*, and the acidulated water. A copper wire ending in a cup containing mercury is soldered to the zinc cylinder. A similar mercury cup is attached to the copper vessel. In placing the zinc cylinder within the copper vessel, care must be taken that the zinc does not come in contact with the copper. This is most easily prevented by means of pieces of cork. If we wish to complete the circuit, we must connect the mercury cups by a metallic wire. This apparatus has this advantage that it enables the zinc to be very conveniently cleaned.

FIG. 401. FIG. 402.



Hare's Calorimotor represented in Figs. 403 and 404, is used

FIG. 403.

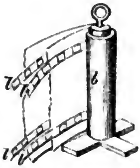


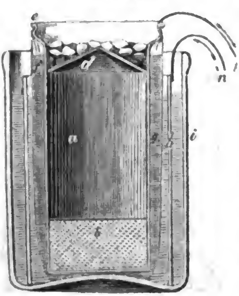
FIG. 404.

where we have to act upon a large surface of metal plates. On a wooden cylinder *b*, about 3 inches in diameter, and from a foot to a foot and a half in height there are two plates, one of zinc and the other of copper, rolled up in the same manner, and separated by cloth strips *l*. We thus obtain a pair of plates of 50 to 60 square feet in area. The name Calorimotor is applied to this apparatus from its special property of making metal wires red hot, and even fusing them.

In all the circuits we have hitherto described, whether simple or compound, the action is very energetic immediately after immersion into the acid fluid, but it very rapidly diminishes. This variation in the current, always occasions great disturbance in experiments made to compare the force of different currents. The *constant batteries* which have lately come into use, are, however, free from this inconvenience. We must here limit ourselves to a description of the most important constant circuits, reserving for a subsequent occasion an exposition of the theory as well as the causes that contribute to the rapid diminution of the force of the current in ordinary circuits.

As inventor of the constant circuit, *Becquerel's* name deserves mention. Fig. 405 represents an element of *Becquerel's* constant circuit; it consists of a hollow cylinder *a* made of thin copper sheeting loaded with some sand *b* and closed on all sides. The bottom *c* is even, the top *d* conical, having over it a rim *e* perforated with numerous holes. The whole cylinder is surrounded by a bladder *g*, fastened to the rim *e* above the holes *f*. We now pour a solution of sulphate of copper on the cone *d*, and this running through the holes *f*, fills the space between the bladder and the cylinder *a*; a few crystals of sulphate of copper (blue vitriol) are laid upon the cone *d*, being gradually dissolved by the fluid flowing over them. The bladder

FIG. 405.



s enclosed in a hollow cylinder *h*, slit lengthwise so that it may e widened or contracted at will. This zinc cylinder, as well as he bladder containing the copper cylinder and the blue vitriol olution are immersed in a vessel *i*, made either of glass or porceain, which contains dilute sulphuric acid, or a solution of sulphate f zinc, or of muriate of soda. Two strong copper wires *p* and *n*, ne of which is soldered to the zinc cylinder and the other to the opper, form the two poles of the element. If we establish a netallic connection between these two poles the electric current vill begin to circulate.

Daniel's constant battery is only a modification of *Becquerel's* nvention.

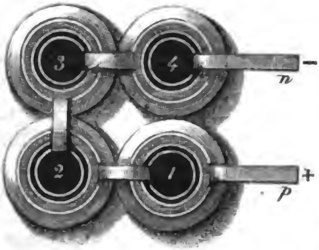
In the *Bunsen* battery, the place of the copper is supplied by arbon, which is still more negatively electric, and is used here n the form of hollow cylinders. A hollow cylinder of this kind, pen at the bottom, 120^{mm} in height and 64^{mm} in diameter, having ts sides about 6^{mm} in thickness is placed in a glass vessel, as seen in Fig. 406, somewhat contracted towards the top, so as to have no great interstice between the carbon and the glass, the cylinder standing consequently quite fast in the glass. We now place in the hollow of the carbon cylinder, a hollow cylinder of porous clay, closed at the bottom, and having at the height of about 105^{mm}, such a diameter as to make it fit into the cavity of the carbon cylinder, and to leave a very mall space between the clay and the carbon. The clay cavity s filled with dilute sulphuric acid, but the glass contains so much oncentrated nitric acid, that when the clay cylinder is put in, lmost the whole free space of the glass is filled to the narrow eck of the vessel with the last named fluid.

FIG. 406.

The upper end of the carbon cylinder projects beyond the lass and is slightly conical, so that a likewise slightly conical ing of zinc *a* can be fastened to it. This ring supports by means f a zinc brace *b*, a hollow zinc cylinder *c* about 87^{mm} in height nd 40^{mm} in diameter. This cylinder *c* is suspended in the clay avity of the next glass in the dilute sulphuric acid.

Fig. 407 clearly exhibits the manner in which one pair of zinc lates is connected with the next, the diagrams showing the outlines

FIG. 407.



of four pairs. The carbon cylinders are distinguished by different horizontal bands. Within each carbon cylinder, we see two white rings in the figure; the outer one represents the clay cylinder seen from above, the inner one the zinc cylinder. The zinc cylinder of the first glass, is connected by a strip with the zinc ring encircling the charcoal cylinder of the second glass. In like manner, a zinc strip connects the zinc cylinder of the second glass with the zinc ring of the third, and a third strip joins the third zinc cylinder to the fourth zinc ring. The ring placed upon the first carbon cylinder ends in a zinc strip, serving as a positive pole; the zinc strip *n*, with which the zinc cylinder terminates in the fourth glass, is the negative pole of the circuit.

In the same manner we may construct circuits of any number of pairs.

In each separate pair, the + current passes from the zinc ring enclosing the carbon through the strip to the zinc cylinder of the next glass, from the latter through the dilute sulphuric acid, the pores of the clay cavity and the nitric acid to the next piece of carbon, &c.

The carbon used for these cylinders is prepared in a peculiar manner from coal and coke; but we cannot enter here into an exposition of the process.

Grove's battery is very similar in its construction to *Bunsen's*, the difference between them being principally that in the former platinum is used instead of carbon.

CHAPTER II.

ACTIONS OF THE GALVANIC CURRENT.

Physiological actions of galvanic piles.—The convulsions of the rves produced by the electricity of the voltaic piles, are not less lent than those occasioned by common electric batteries; their ensity depending upon the number of pairs of plates, that is on the amount of tension. To conduct the charge of the piles ough the human body, it is necessary to moisten the hands, as instance with salt water, the epidermis being a very bad conctor. On touching both poles of a pile of 20 to 30 pairs of ites with dry fingers, we do not experience the slightest shock, t the charge is perceptible the instant we wet the hands. The arge of a pile of 80 to 100 pairs of plates is very marked.

We feel a shock at the moment in which we close the circuit th the fingers; as long as it remains closed, the electric current culates through the body without producing any very marked tion upon the feelings, and it is only with very powerful piles many pairs of plates, that one is conscious of a burning tingling nsation at the places where the current enters the body. A cond shock is felt, however, at the moment in which the current reopened; but this, termed the *separation shock*, is much weaker an the *closing shock*.

Even a simple current will make a lightning-like appearance sh before the eyes. We may make the experiment in various ays; thus, for instance, we may bring a silver plate towards the ipil of the eye, or towards the eye-lid, which must be previously ell moistened, and then touch the plate with a piece of zinc held the moistened hand, or retained in the mouth. On conducting e current of a pile through the eyes, the appearance of light ill be stronger.

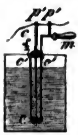
If now we lay a piece of zinc above, and a piece of silver under e tongue, and then bring the upper extremities of both metals contact, we shall perceive a peculiarly bitter taste.

Generation of light and heat by galvanic currents.—Galvanic irrents, like the electricity of friction, produce heat and light.

If we conduct a galvanic current through a metal wire, it will

be heated; the connecting wire must, however, be very short and thin, to yield a powerful action. The intensity of the heat will depend upon the size, and not on the number of the metal plates. To make metallic wires red hot, it is only necessary to use a simple current of large surface, as represented in Fig. 408. A *Bunsen's* battery is also well adapted for this experiment. The larger the acting surface of the galvanic apparatus, the greater may be the thickness of the wires that are to be made red hot and melted.

FIG. 408.



Iron and steel wire attain a white heat, melt, and burn with the emission of vivid sparks.

Platinum wires become vividly glowing and melt away, if they are made short and thin enough for the circuit used in the experiment.

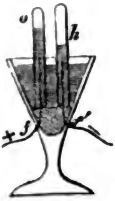
Thin gold-leaf volatilizes, and as one cannot use it for touching the poles, without its being converted into vapour at the place of contact, the current is constantly interrupted and again closed, by which means we see emitted a number of small, shining sparks of a greenish colour. Silver tissue exhibits the same phenomena.

If we fasten to each of the poles of a galvanic circuit, pointed pieces of carbon (of the kind and size used in the carbon cylinders of *Bunsen's* battery), we shall, as soon as these points come into contact, perceive an uncommonly glittering light. This bright light can be seen by a *Bunsen's* battery of only four elements: a small, brightly luminous star appearing where the points of the charcoal come into contact with each other. By increasing the number of the elements, the splendour of the appearance considerably increases; and thus, in a circuit consisting of from 30 to 50 elements, we may obtain a light far exceeding in brightness *Drummond's* hydro-oxygen light. By the application of this number of pairs of plates, we may remove the points of the pieces of carbon tolerably far from each other, if only the current passes, and we may thus obtain a splendid bow of light, formed by the glowing particles of the charcoal which pass from one pole to the other.

Chemical actions of the voltaic pile.—The first, and most important chemical action of the pile, was discovered by *Carlisle* and *Nicholson*, at the beginning of the present century, (30th of April, 1800). These two natural philosophers had hastily built up a pile of coins, zinc plates, and damp pieces of pasteboard,

order to repeat some of the experiments of *Volta*. After a few als, the smell of hydrogen became obvious, and *Nicholson* was l by this to the happy idea of suffering the current to pass rough a tube filled with water, into which fluid he plunged both les, holding them at some distance apart. The hydrogen gas on rose to the negative pole in small globules, whilst the zinc re, connected with the positive pole, became oxidised. If, hower, a platinum, or silver wire was used in the place of the zinc, did not oxidise; but the oxygen likewise rose in bubbles to the rface. This water was at length directly decomposed into its ments. *Cavendish* certainly had already shown that oxygen and drogen combine to form water; but notwithstanding all efforts ade for the purpose, no one had yet succeeded in accomplishing e direct decomposition of water. A suitable apparatus for the composition of water is represented in Fig. 409. It consists of a glass, in the bottom of which two platinum wires *f* and *f'* are inserted, without being suffered to touch each other. Two glass bells, *o* and *h*, are filled with water, and set inverted in the glass, so that one may cover each of the wires. As soon as the wires *f* and *f'*, are brought into contact with the poles of the circuit, bubbles of gas are developed in large quantities. Pure oxygen gas always rises in the bell at the + pole, and hydrogen gas at the her. It will, of course, be understood that the water in the ell must not be separated from that in the vessel, so that the urrent may pass through the fluid from one wire to the other.

FIG. 409.

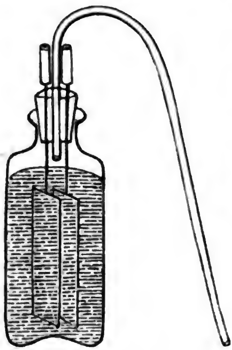


The development of gas will increase in quantity, as the istance between the polar wires *f* and *f'* is diminished, and ccording to the amount of surface of the metal standing contact with the water. In many apparatus, therefore, rving for the decomposition of water, the wires have been placed by platinum plates.

Distilled and perfectly pure water is, however, but slowly ecomposed in this manner; but as soon as we pour a few drops f any acid, or dissolve a few grains of salt in the water, by which e conducting power of the fluid is considerably heightened, a ery strong action begins, affording, in a short time, a large uantity of gas. We will subsequently consider how the quantity f the gas developed, depends upon the force of the current.

The apparatus shown in Fig. 410, may be used where we do not

FIG. 410.

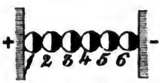


care to have the two kinds of gas separated, as it enables us to decompose a larger quantity of water, owing to the greater vicinity of two large polar plates of platinum. The explosive gas escapes through a curved tube, and on immersing the opening of the latter under water, we may collect the gas, or make the escaping bubbles detonate.

The quantity of oxygen liberated at the + pole, and collected in the tube *o*, (Fig. 409), has only half the volume of the hydrogen, which is liberated at the other pole, and rises in the tube *h*. The gases are, therefore, evolved exactly in the same proportion as they combine with water. Water, as is well known, consists of 1 equivalent of oxygen, + 1 equivalent of hydrogen. But one equivalent of hydrogen occupies, other things being the same, twice as large a space as one equivalent of oxygen. The gases evolved from the pile will, therefore, when combined together, again yield water.

Grotthuss has given the following explanation of this remarkable phenomenon, which is now generally admitted by natural philosophers to be correct. When hydrogen gas is combined with oxygen to form water, the atoms of the oxygen become negatively electric in the intimate connection established between the smaller particles, while the atoms of the hydrogen are positively electric; but owing to the uniform distribution of the particles of both substances, the combination does not, of course, exhibit any liberated electricity. If now water be placed between the poles of a galvanic circuit, the + pole will act in such a manner upon the most contiguous particles of water, that the — constituent will be attracted, and turned to the + pole, whilst the repelled atom of water of the first molecule of water will be turned away from the + pole. The water-particle 1, Fig. 411, will act upon the particle 2, in such a manner as to turn its elements to the same side; in a similar way 2 will act upon 3, &c. It therefore follows, that all the molecules of water between the two poles, will turn their atoms of oxygen to the + pole, and their atoms of hydrogen to the — pole, somewhat as shown in

FIG. 411.



. 411, where the circle represents particles of water, the black the atom of hydrogen, and the white half the atom of oxygen. iow the attraction exercised by the + pole upon the atom of gen of the water-particle 1, be strong enough, it will tear it ently from the atom of hydrogen; this latter will again combine the oxygen of the water-particle 2; the hydrogen of 2 in with the oxygen of 3, &c. In this manner, a constant omposition and recombination of the water will go on along the le line between the poles, but it is only at the poles that its stituents can be liberated.

decomposition of water occurs in the cells of the galvanic uit, exactly in the same manner as between the poles.

)xides are decomposed by the galvanic circle in the same nner as water. Oxygen appears at the + pole, the radical at — pole. The following experiment will answer for metallic des that are reducible: if we strew a little dry pulverised oxide n a platinum plate, brought in connection with the + pole of pile, and touch the powder with the — wire, we shall soon small metallic globules appear at the extremities of the wire. ides less easy of being reduced must be somewhat moistened, ecially if they are in a pulverised state. The water will tainly also be partially decomposed, but this will only serve to rease the capacity for conducting electricity. After a time we ll see, when the pile is strong enough, small metallic globules, pearing at the — pole.

A new epoch in science began with the year 1807, when *Davy*, means of a galvanic pile, made the discovery that alcalies could decomposed, which had, until then, been regarded as simple lies. Alcalies and earths were thus ranged in the class of des, and chemistry enriched by the acquisition of two new tallic bodies, potassium and sodium. A very strong battery is cessary to decompose potash. If we make the experiment in manner above indicated, we shall see numerous globules of tal appear at the negative pole, and again vanish, with the ission of sparks. This is potassium, liberated in the decompo-ion of potash. Its affinity to oxygen is, however, so great, that being brought into contact with the air, it immediately oxidizes; being brought into contact with water, it abstracts the oxygen, d inflames the hydrogen gas, and has the appearance of fire. tassium must, therefore, not be kept in a fluid containing

oxygen. Petroleum, or naptha, composed of carbon and hydrogen, is generally used for this purpose.

Seebeck has proposed a means by which the potassium evolved by means of a galvanic pile, may be collected with more certainty. A hollow is made in the piece of caustic potash we wish to decompose, and mercury poured into it. The potash is then laid upon a piece of platinum in connection with the + pole of the pile, while the — wire plunges into the mercury. The decomposition immediately begins, the oxygen is liberated in the platinum, while the potassium, combining with the mercury forms a tolerably consistent amalgam. We may then separate the mercury, by distillation in an atmosphere of petroleum vapour, and thus obtain the potassium in a pure condition.

Salts can also be decomposed by means of the galvanic current, the acid appearing at the +, and the earth, or base, at the — pole. The decomposition of salts may be made perceptible in the following manner. We fill a V-formed curved tube (Fig. 412) with a saline solution, which is coloured violet by tincture of litmus. If now we plunge the + polar wire into the fluid on the one side, and the — wire on the other side, the fluid will be red at the +, and blue at the — pole. On changing the poles, the original violet hue will be only restored by degrees, red appearing where the wire was blue before the inversion of the poles, and *vice versâ*.

FIG. 412.

If we pour a saline solution into two contiguous vessels, connected by a moist asbestus cloth, or by an A-shaped syphon, filled with the fluid, and then plunge the + polar wire into the one vessel, and the — wire into the other, the decomposition will go on in the same manner; and after a time, the acid will be in the vessel into which the + wire has been immersed, and the base in the other. Even if we pour the earthy solution into the vessel *A* containing the + polar wire, and the acid into the other *B*, the acid will, after a time, be in *A*, and the base in *B*. This experiment has been modified in various ways.

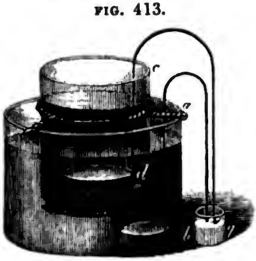
A saline solution is not always decomposed into the acid and base by the galvanic current, there appearing in the decomposition, frequently, only one or other of these bodies. A solution of sulphate of copper, for instance, is so decomposed that the copper separates at the — pole, whilst the oxygen of the oxide of copper

no longer remains in its former combination on the other side. This decomposition of sulphate of copper is beautifully exhibited in the constant circuit of *Becquerel* and *Daniel*, already described. When the circuit is closed, the + current passes from the zinc through the dilute sulphuric acid, then through the solution of sulphate of copper to the copper. If the zinc become + electric in contact with the copper, and the latter —, the zinc is, of course, the +, and the copper the — pole, the + current passes, therefore, through the zinc, and the — current through the copper into the fluid. On the one side of the partition water is decomposed, the oxygen passes over to the zinc, forming oxide of zinc, which, dissolving in the acid, forms sulphate of zinc. The hydrogen gas goes to the partition, where it forms, as it were, the + pole for the current passing into the other fluid. The oxide of copper is decomposed by this current, the oxygen of the oxide passes to the + pole, consequently, to the wall of partition, where it combines with the liberated hydrogen to form water, whilst the copper at the — pole, that is, at the copper plate, is separated in the metallic form.

A highly interesting application has been made of this metallic precipitate of copper, and is known under the name of galvano-plastics (electrotype); it is only necessary to give a definite form to the — elements of a combination of this kind, to obtain impressions of this form in metallic copper.

It is necessary to modify somewhat the form of the *Becquerel* circuit before applying it for this purpose. The apparatus represented in Fig. 413, is especially well adapted for the multiplication of coins, medals, &c. *a b* is a glass vessel open at the top, about 6-8 inches in diameter. Within this hangs a second narrower glass vessel *c d* likewise opening at the top, but closed at the bottom by having a bladder tied to it. Somewhat above the middle, a wire is tightly bound round the inner vessel, which it lifts up in such a manner, that the bladder is raised from 1,5 to 2 inches above the bottom, the wire branching out in three arms, which are attached to the rim of the outer vessel. The inner vessel is filled with a very dilute sulphuric acid, while the space intervening between the inner and outer

FIG. 413.



cylinder is filled with a solution of sulphate of copper. Two pieces of wood laid cross-ways support in the sulphuric acid a zinc block, to which a copper wire is soldered, connecting the zinc block with the mercury-cup *q*. A second copper wire passes from this cup to the form lying in the solution of sulphate of copper, which, of course, must be made of a substance more electro-negative than zinc.

Such a form may be procured by taking an impression of a coin with *Rose's* fusible metal, and still more easily by means of wax or stearine. These two substances must be fused together with finely pulverised *graphite*, and the liquid then poured on the metal, which must be protected by a rim of paper, when a very beautiful form is obtained.

This matrix, however, is not a conductor, and only becomes so by covering the surface, which is to receive the copper with a thin delicate layer of fine copper bronze. This coating, which may be laid on with a fine brush, does not in any way take from the purity and sharpness of the outlines. The matrix must be plunged into the solution with its conducting surface turned upward. The copper wire requires only to be in contact with the fine graphite layer.

The portion of the copper wire plunged in the solution of sulphate of copper must be covered with shell-lac, or sealing-wax, to prevent metallic copper from being deposited upon this wire, which deposition must be prevented except where it is attached to the matrix.

The current circulating through the apparatus is very weak; the copper deposits itself slowly upon the copper surface, and subsequently upon the copper wire; it is, therefore, necessary from time to time to place the wire at a different part of the mould. The layer of copper will be thick enough, and may be removed in one or more days according to the strength of the current. The copper deposit is most regular with a weak current, on which account the fluid in which the zinc block is plunged should be only slightly acid.

The solution of sulphate of copper becomes lighter in colour in proportion to the copper deposited from it. It is necessary occasionally to renew the solution as it becomes exhausted.

It is often better to place the solution of sulphate of copper with the mould in the inner vessel, and the acid with the zinc block in the outer vessel.

Many important applications of galvano-plastics have been made

within the last few years; by this means impressions of woodcuts have been taken, which retain all the purity and sharpness of the original outlines, and thus, as many fac-similes as we like may be taken of the original, without any difference being perceptible between the first and last impressions. The woodcuts of the original German edition of this work, from which those in our present translation are copied, were impressed by copper type of this description. A graved copper plate will not bear many impressions being taken of it, without manifesting a decided deterioration in the later impressions. Hence, the value of the proof-impression, and hence, the reason that steel engraving is so much valued, for a steel plate will bear a much larger number of impressions being taken of it. Steel, however, offers decided disadvantages with reference to art, for owing to the hardness of its texture it opposes great difficulties to the artist, who cannot possibly complete as perfect a work on steel as on copper. Now, however, a means has been devised of multiplying copper plates, even when of a large size, by the galvano-plastic process, so that the impressions of the copies, of which we may have an unlimited number, are quite equal to the original plates.

Kobell of Munich has proposed a method by which pictures drawn in bistre or Indian ink may be multiplied by galvano plastically. A copper plate silvered over, is used for painting on, and the colour prepared for the purpose, is an ochre or coke rubbed up in a solution of wax and oil of turpentine, adding a little Dammara varnish. This colour is laid on the plate in such a way, that the brightest lights remain free, the paint laid on thicker in proportion to the depth of shadow required. As soon as the picture is finished, a wash of finely pulverised graphite is laid on with a fine brush, and the plate is put into the galvano-plastic apparatus. By degrees the copper is precipitated upon the painted plate, forming a second copper plate on which all the lights appear smooth, and the shadows are deeply impressed; this plate will now yield, if treated like a graved copper plate, impressions similar to an Indian ink drawing. *Thayer*, of Vienna, has brought this method to great perfection, and there is reason to expect that it will prove of still greater practical importance to art.

In the same manner as copper is precipitated at the negative pole of the circuit, by a galvanic process from a solution of sulphate of copper, other metals, as gold, silver, platinum, &c.,

are deposited at the negative pole from suitable solutions, and we may thus gild and silver other metals, &c. It would lead us beyond our proper limits were we to enlarge further upon this subject.

An interesting illustration of metallic precipitations is presented by the *Nobili's coloured rings*. If we pour a few drops of a solution of acetate of lead upon a silver plate, and then touch the silver in the middle of the fluid with a small piece of zinc, several concentric coloured rings will be formed around the places of contact. These rings appear still more beautiful on putting the fluid between the poles of a pile composed of many plates, flattening the one pole, and pointing the other, and then turning the latter in such a manner to the former, that the electric current passes through the fluid from the flattened to the pointed pole, or *vice versâ*. *Nobili* obtained similar phenomena of colours with other fluids.

Chlorides, iodides, and bromides of metals are simply decomposed by the electric current, the metal being deposited at the negative, and the chlorine, iodine, and bromine, at the positive pole. The weakest current is capable of decomposing iodide of potassium.

On exposing aqueous solutions to the action of the electric current, the result of the decomposition will often be modified by the presence of the water. To avoid this, Faraday has reduced many bodies to a fluid state by fusion, and thus exposed them to the action of the current. He thus decomposed chloride of lead, chloride of silver, &c., laying them upon a glass plate and fusing them over a spirit lamp, and then immersing both polar wires into the fluid mass. If polar wires of silver were plunged in fluid chloride of silver, the silver would be deposited at the — pole, which had attached itself to the wire, whilst the other silver wire would be dissolved by the liberated chlorine.

We have hitherto only spoken of decompositions produced by the galvanic current, but this current also favours to chemical combinations. If we bring any easily oxidisable metal, as zinc, for instance, near the + polar wire, the metal will very easily combine with the oxygen separated from the water, zinc only dissolves slowly in diluted sulphuric acid, if it be quite chemically pure; on touching it with a piece of silver, a marked development of gas instantly begins to take place at the silver, while the zinc combines with the oxygen to form oxide which is dissolved by the acid.

f the polar wires of a galvanic battery be made of zinc, and n immersed in acidulated water, the decomposition of the water go on precisely as if platinum or copper wires were used. The lrogen gas will be separated at the wire of the negative pole, ch will not be affected by the acid, as would otherwise be the e if it were not made negatively electric by its connection with pile, and thus protected from oxidation; the wire of the pola- e pole, on the contrary, will be so much the more rapidly acted on.

A metal affected by an acid or any other fluid can be protected m oxidation by being brought into connection with a metal itively electrified, so as to form the — pole of a simple circuit.

Whilst the current arising from the contact of two metals nged in the same fluid increases the affinity of one of these one element of the fluid, the power of the other metal to un- go the same changes is proportionally diminished. Thus, when zinc and a copper plate come into contact in a dilute acid, zinc will oxidize more rapidly, and the copper less than would erwise be the case. *Davy's* experiments on the preservation the coppering of ships affords a beautiful illustration of this nciple. A copper plate when immersed in sea-water is exposed a rapid oxidation; but if the copper be brought into contact with c or iron, these metals will be dissolved, and the copper thus otected. *Davy* has ascertained that a piece of zinc of the size the head of a small nail is sufficient to protect 40 to 50 square hes of copper.

It has unfortunately been shown, however, that this excellent de of preserving copper cannot be practically made use of, as pper must be acted upon to a certain extent, in order to save it m being injured by the adhesion of sea-weed and marine imals.

The same principle has been applied by *von Althaus* to prevent e rusting of the iron pans used in evaporating brine. Here, wever, the protecting zinc could not be applied to the pans emselves, as the sulphate of zinc would distribute itself through e brine, he therefore separated the corners of the pans by a ard, and filled these spaces with zinc, whose bottoms were formed th iron plates. Thus the zinc is in metallic connection with e iron, and the fluid passes in sufficient quantity through the od to the zinc to complete the circuit, while the sulphate of nc engendered cannot destroy the purity of the solution of salt.

By this means, evaporation was effected at a lower temperature, and a considerable saving made in the expenditure of fuel.

The electro-chemical theory.—The hitherto described phenomena exhibit remarkable relations between chemical and electrical forces. It had already been vaguely conjectured, that electrical forces were concerned in chemical phenomena; this view was, however, only confirmed when the decomposition of water was effected by the voltaic battery; that is to say, it was reserved for *Davy* and *Berzelius* to develop these views; and they established the electro-chemical theory, according to which, we must seek for the fundamental cause of chemical combinations in electric attraction. Although it may not be fully proved, that chemical affinity and electrical attraction are perfectly identical, it must be confessed, that this theory combines many facts into one connecting bond in a manner that cannot be refuted by experience.

As zinc and copper, when brought into contact with each other become oppositely electric, so also according to the electro-chemical theory, the atoms of every two elements become oppositely electric when brought into contact with each other; in short, all elements are, according to the signification already given at page 363, members of the series of tension. The extremes of this perfectly complete series are oxygen and potassium, the former being the —, and the latter the + extremity. The following is the complete series of tension.

—

Oxygen	Bromine
Sulphur	Iodine
Selenium	Fluorine
Tellurium	Phosphorus
Nitrogen	Arsenic
Chlorine	Carbon
Chromium	Cerium
Molybdanum	Lanthenium
Borax	Yttrium
Vanadium	Cobalt
Tungsten	Nickel
Antimony	Iron
Tantalium	Cadmium
Titanium	Zinc
Silicium	Hydrogen
Osmium	Manganese

Gold	Zirconium
Iridium	Aluminum
Rhodium	Thorine
Platinum	Beryllium
Palladium	Magnesium
Mercury	Calcium
Silver	Strontium
Copper	Barium
Uranium	Lithium
Bismuth	Sodium
Lead	Potassium.
	+

This series contains all the simple substances, and to each its place is assigned, although there is still much uncertainty in this respect, and the position of most bodies in the series of tension is only approximatively, but not accurately determined. This position has only been ascertained by direct experiment for a very few bodies; the place of the majority having been conjectured from their chemical relation.

According to the electro-chemical theory, the atoms of the elements are not electrical in themselves, but become so on being brought into contact with others, whence it happens that the same body may at one time be +, and at another — electric. Thus, for instance, sulphur in combination with oxygen is the electro-positive, and in conjunction with hydrogen the electro-negative element.

We have seen that two heterogeneous metal plates brought into contact with each other become oppositely electric; but, that the greatest part of the electricity developed remains combined on the surface of contact; the same is the case with chemical combinations. If, for instance, a particle of oxygen and one of hydrogen come into contact, the former will become —, and the latter + electric, both electricities will attract each other, and combine almost perfectly, owing to their close approximation. If, however, there is a little free + electricity on the one particle, and — electricity on the other, the chemical combination cannot give any evidence of free electricity, owing to the + and — particles being uniformly distributed; thus, wherever we lay our hands on the body an equal number of + and — electric particles will be touched.

In the first place, the simple substances combine to form binary compounds. The compound bodies, as the oxygen, sulphur, and chlorine combinations, exhibit among themselves a relation similar

to that of simple substances; these binary combinations of the simple elements, oxides, sulphurets, and chlorides, &c., which are characterised by negatively electric properties, and at the same time capable of entering into combinations of a higher order, are termed *acids;* while those constituting the part of the positively electric constituents are called *saliable bases.*

The character of an acid is generally so much the more strongly expressed in proportion to the contiguity of its elements to the negative end of the scale of tension, hence sulphuric acid is the strongest of all acids. Oxygen forms acids in connection with the bodies standing at the head of the above series, and bases with the elements at the positive end; thus potassium is the strongest of all bases.

When the same body combines in several different proportions with oxygen, the combination will be so much the more negatively electric, because it will assume more of the acid, and less of the properties of a base, in proportion as the electro-negative element, the oxygen, predominates. Thus, 1 equivalent of manganese combined with 1 equivalent of oxygen forms oxide of manganese, which possesses the properties of a base, whilst 1 equivalent of manganese + 3 equivalents oxygen form manganic acid.

The electro-chemical theory does not in its present limits embrace an explanation of all chemical phenomena; but the classification of bodies founded upon it agrees sufficiently with their relations, so as to give a clear insight into chemical laws.

The electrolytic law.—No electric current, or comparatively only a very weak one can pass through a fluid without its passage being attended by chemical decomposition. Such a decomposition as this occurs in every cell of every galvanic apparatus, as long as the circuit remains complete, and *Faraday* has shown that the quantity of the electrie current is proportional to the decomposition taking place in each individual cell.

It cannot be denied that an intimate relation exists between the passage of the electric current through fluids and their decomposition, and it may even be asserted, that the passage of the electricity is effected by chemical decomposition. The positive current passes in every cell from the zinc through the fluid to the copper, but the particles of the hydrogen pass in the same direction; they are the conductors of the + electricity, which is conveyed by them to the copper plate. Indeed, we have seen, that in accordance with the principles of the electro-chemical theory, the

elements are held firmly together in each atom of water because oxygen and hydrogen brought into contact become oppositely electric, and because these opposite electricities of the elements of water mutually combine with each other. When a particle of hydrogen is separated from its oxygen, all its combined electricity will be liberated; it will be, however, immediately recombined when the hydrogen, on the other hand, combines with another particle of oxygen, and thus each atom of hydrogen will carry off its combined + electricity, whilst at the same time its positive electricity will be liberated at the — pole with the hydrogen.

Whilst the ordinary zinc of commerce is rapidly dissolved when plunged into dilute sulphuric acid, chemically pure zinc or amalgamated zinc will remain unaffected in the same fluid. If we construct a galvanic circuit with chemically pure, or amalgamated zinc plates, no decomposition can possibly occur in such a circuit while open. But the moment it is closed, a decomposition of water begins in every cell; there is, however, no more water decomposed nor zinc dissolved than is necessary to conduct the circulating current; the quantity of the dissolved zinc must therefore stand in a definite relation to this current. *Faraday* made use of the current of such a circuit for the decomposition of water, and ascertained definitively the amount of explosive gas evolved in a given time. It was thus found that, for each equal portion of hydrogen gas liberated between the polar wires, or rather the plates of the poles 32,3 equal portions of zinc were dissolved in each cell. But now the weights of the chemical equivalents of hydrogen and zinc are to each other as 12,48 to 403,23, or as 1 to 32,3. For every equivalent of hydrogen, therefore, evolved in the decomposing cells 1 equivalent of zinc must be dissolved in each cell of the circuit.

If the same current be conducted through 4 decomposing cells, of which the first contains water, the second chloride of silver, the third chloride of lead, the fourth chloride of tin, all in a fluid condition, the quantities of hydrogen gas, silver, lead, and tin, which are precipitated at the four — poles are to each other, as 1: 108: 103,6: 57,9, whilst at the + poles oxygen and chlorine are separated in the proportions of 8 : 35,4. Similar facts have been demonstrated for many other composite bodies.

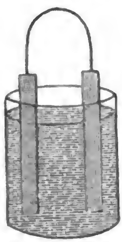
It follows from these facts, that the chemical equivalents represent those relative weights of the substances which assume

an equally strong electric polarity in connection with one and the same element.

Theory of constant circuits.—The common voltaic circuit in which only one fluid is used, gives, as we have already seen, an uncommonly strong current at the first moment; this, however, soon abates in intensity, whilst in the *Becquerel* circuits, *Daniels'*, *Groves'*, *Bunsen's* apparatus, the current continues with unabated force. Now that we have learnt to understand the chemical phenomena in the circuit, we may be able to explain why the current remains constant in the one kind of apparatus, and loses rapidly its intensity in the other.

A zinc and a copper plate united by a copper wire at the top, are plunged into a vessel (Fig. 414) filled with a solution of sulphate of zinc. At first a tolerably strong current will be engendered, which, however, will soon abate, and finally entirely cease. The reason of this cessation will be soon understood on considering the process of the decomposition; the oxide of zinc of the solution is soon decomposed, the oxygen attaches itself to the zinc plate in order to form a new oxide, whilst on the other side metallic zinc is precipitated on the copper plate; after a time the copper plate becomes wholly covered over with zinc, when the current of course ceases. The copper is now no longer in connection with the fluid, but there is zinc on both sides of the copper, and of the fluid; the copper becomes negatively excited where it is soldered to the zinc plate, but this excitement does not occasion any current, since the newly formed zinc coating gives rise to a totally opposite one.

FIG. 414.



If we take dilute sulphuric acid instead of the solution of oxide of zinc, the water of the fluid between the zinc and copper plate will be decomposed; in the place of the zinc which is precipitated on the copper plate, as in the former case, the hydrogen will now be liberated, the copper plate will be covered with a coating of hydrogen, which will not, however, come into such intimate connection with the copper as in the former case, and cannot, therefore, so completely prevent the fluid from coming into contact with the copper plate as in the other. A total cessation of the current is, therefore, not possible here; but the separation of hydrogen (which, according

Buff's experiments on the scale of tension, stands below zinc), casions a diminution of the intensity of the current in the same ıy as in the other case the deposition of zinc had done.

If the reason of the diminution of the current in ordinary rcuits be rightly understood, it will be easy to find a method avoiding this occurrence; it being only necessary to devise me arrangement by which the separation of hydrogen on the pper and platinum plates may be prevented, so that these plates ay always remain in contact with the fluid in the same manner.

In *Becquerel's* and *Daniel's* circuit, metallic copper is deposited ı the copper plates instead of hydrogen, and thus a pure copper rface is always left in contact with the fluid. In *Grove's* battery, e platinum is surrounded by a layer of nitric acid, which likewise rculates round the charcoal in *Bunsen's* apparatus; this acid revents the separation of the hydrogen on the platinum or the ıarcoal, for, at the moment of their origin, the deposited particles hydrogen are again oxidised, and nitrous acid formed.

This seems to be the most suitable place to say a few words ncerning the various theories that have been advanced in explanaon of the electrical phenomena of galvanic batteries, as they have rmed the subject of the most animated discussions between ifferent scientific men.

The oldest of these is the *theory of contact*, established by *Volta*, cording to which, the contact of different metals is the only urce of the electricity of the pile. *Volta* had devoted especial tention to the study of the actions of tension in batteries, and ıese are explained more satisfactorily according to his theory than ıat of any other. He doubtlessly disregarded chemical phenomena om being wholly ignorant of, or but slightly acquainted with ıem, and hence it arises that he did not devote sufficient attention the part played by the fluids in the circuit, considering them ıerely as conductors, and not as electromotors.

When the chemical actions of the battery were better known ıd more accurately observed, the voltaic theory of contact was ot satisfactory, and it became necessary either to corroborate ıd enlarge upon it, in order to admit of its embracing the ewly discovered facts, or to set it wholly aside, and to form an ıtirely new hypothesis. Both methods have been adopted, and ıat by distinguished natural philosophers.

The opponents of the theory of contact, among whom *Faraday* ıust be specially noticed, consider the chemical action exerted

by the fluid upon the metal as the source of the electric current of the circuit.

Faraday was likewise induced by his theoretical views to introduce a new nomenclature, calling the poles "Electrodes," or the courses pursued by the electric current in entering the decomposing fluid, the positive pole "Anode," and the negative pole "Cathode." The constituents of the electrolyte (the decomposed body) are according to his nomenclature *Ions,* the *Cathion* being the element separated at the cathode, and the *Anion* that which is found at the anode.

It will not surprise us that so much misconception and difference of opinion should exist with respect to the source of the electricity in the circuit, when we consider how little is known to us of the actual nature of electricity. What do we know concerning the generation of electricity by friction beyond the simple fact? The reason of the difference of opinion that existed regarding galvanism, evidently arose from *Volta's* disregard of the influence exercised by chemistry. This deficiency, or rather the partiality of this view could not long escape observation; but while many learned men were striving to point out the importance of this influence, they fell into the opposite extreme of ascribing every effect to chemistry, and neglected those well proved facts which constituted the basis of the theory of contact, some even suffered themselves to be so far led astray as to question the correctness of *Volta's* fundamental experiments, or explained them by the hypothesis that the precious metals underwent oxidation.

The adherents of both theories were most zealously active in advancing proofs of the correctness of their own opinions, and to these efforts we are principally indebted for the advance that has been made in the science of galvanism. *Fechner,* above all, deserves praise for having established beyond doubt the correctness of *Volta's* fundamental experiments, and thus justified the views concerning the excitement of electricity in various metals. *Faraday,* on his side, has shown that galvanic currents may be produced without the contact of heterogeneous metals, that the chemical decomposition of the fluid of the pile is proportional to the quantity of the electrical current, and that, consequently, this decomposition stands in the closest connection with the formation of the current in the hydro-electric circuit.

As a theory of galvanism should, if possible, embrace *all* the phenomena of the circuit, we can scarcely look for truth in the

extreme views of either party. It seems, therefore, most suitable to the present stage of science to adopt some modified theory of contact as given above, since by this means we shall be best able to consider from one common point of view the different phenomena exhibited in the circuit.

Magnetic actions of the galvanic current.—It had long been known, that under certain circumstances powerful electric charges could affect the magnetic needle; it had, for instance, been observed that the needle of the compass lost the property of directing the course of the ship, if the latter had been struck by lightning; many natural philosophers attempted to produce similar phenomena by the discharge of Leyden jars, and, indeed, some succeeded in altering the magnetic condition of very small needles, either by suffering the spark to pass very near the needle, or the whole force of the discharge pass immediately through it. But all these experiments yielded no regular results, and people remained satisfied with the view that the electric shock acted upon the magnetic needle as the stroke of a hammer. Subsequent experiments were made in galvanic electricity which yielded no better fruit; finally, in the year 1820, *Oersted,* Professor at the University of Copenhagen, discovered a means of causing electricity to act certainly and constantly upon a magnet. He thus opened to the scientific men of all countries a new and extended field of investigation, and never before, perhaps, had science been enriched in a short time with the acquisition of so many new truths.

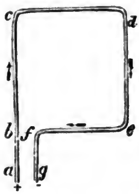
Electricity must be in motion to act upon magnetism when at rest, and in a state of great tension it does not affect the magnet, as does a continuous electric current.

In fact, on bringing a freely suspended magnetic needle to the terminating wire of a pile while the electric current is passing, the needle will deviate. This was the first experiment made by *Oersted,* and it is singular that a similar observation had not long since been accidentally made in the many experiments tried with the pile.

The principal experiment on the action of the galvanic current upon the needle may be made in the following manner: a somewhat thick copper wire must be bent into a square, the sides of which must be from 8 to 10 inches in length; we must now plunge the two extremities of the wire *a b* and *f g*, Fig. 415, into the mercury cup of a galvanic battery of large surface, (as, for instance, into

the cup of the apparatus seen in Figs. 401 and 402), or we must connect them with the poles of the *Bunsen* apparatus, securing them in such a manner that the planes of the square may coincide with the planes of the magnetic meridian. If we assume that the wire end *a b* is plunged into the positively electric mercury cup, the current will circulate in the manner indicated by the arrows. It will ascend from *b* to *c*, but from *c* to *d* it will run in the direction of the magnetic meridian horizontally from south to north, thence will descend from *d* to *e*, and move again in a horizontal line from north to south along the portion of wire *e f*.

FIG. 415.



On holding a magnetic needle exactly over the portion of wire *c d*, it would remain parallel with the wire *c d*, if no action of the current affected it; but the current makes the needle deviate in such a manner that the south pole (that is the one directed towards the north) lies to the east of the magnetic meridian. If we hold the needle under the portion of wire *c d*, the end of the needle turned to the north will be inclined towards the west.

The exactly opposite action is observed in the portion of wire *e f*, in which the current moves in a direction parallel, but opposite to that of the current in *c d*; when the needle is held exactly over *e f* a deviation to the west, and when held below it, a deviation to the east will be observed.

At first great difficulty was experienced in knowing how to express in a few words the relations between the direction of the current and of that of the deviation, this difficulty has, however, been very ingeniously removed by *Ampère*, who has given the following rule for ascertaining at all times the direction of the deviation. Suppose a little figure of a man to be so inserted into the wire that the + current shall enter at the feet and pass out at the head; if then the face of the figure be turned to the needle, the south pole of the latter (the north end) will always be inclined towards the left side.

The figure lies horizontally on the piece of wire *c d*, the head turned to the north, and the feet to the south. If the needle be held over the wire, the figure must lie on its back in order to have the face turned towards the needle, and in this position its left side will be the east. If the needle be held below the wire, the figure must be turned with its face downwards, when the left side will be the west.

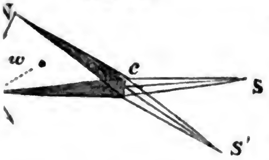
n the piece of wire *e f*, the feet of the figure are turned to the :h and the head to the south; if it be laid on its back, the side will be the west, and of course *vice versâ*, if we lay it ts face.

f a horizontal current moving in the direction of the magnetic idian were to act alone upon the needle, the latter would place lf at right angles to the magnetic meridian; but besides the rent terrestrial magnetism comes into play, and strives to ıg the needle back again into the meridian. The needle , therefore, assume a middle position under the influence of se two forces, making an angle with the magnetic meridian, ch will approach more and more towards a right angle in portion as the force of the current is comparatively greater n the force of the terrestrial magnetism.

The vertically directed current in *b c* and in *d e* causes the dle likewise to deviate, and the direction of this deviation may be found according to *Ampère's* rules. Let us suppose this ıre standing vertically to be turned towards the north end, this l must then incline to the left. Here we must not forget, vever, that the figure must stand upon its feet for an ascending rent, and on its head for a descending one.

It follows from *Ampère's* rule, that the same vertical current ıer attracts or repels the north end of the needle, according to side of the wire on which this pole is placed. In Fig. 416 *S* represents a horizontal needle seen from above, *N* is the north end of the needle, *w* a vertical wire, which naturally seems contracted to a point as seen from above. If now, a + current pass from below upward through the wire, we must suppose the figure to be upright; but if this upright figure turned with its face towards *N*, and the pole *N* in relation to is figure be turned to the left, as the arrow indicates, the needle ll evidently be repelled by the wire. If, however, the needle in the position *N′ S′*, it will evidently be attracted by the re.

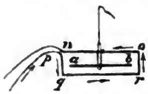
FIG. 416.



The Multiplicator or the Galvanometer.—Shortly after *Oersted* d made his important discovery *Schweigger* constructed his ıltiplicator, the object of which is to multiply the electroıgnetic action of the current. This instrument is actually so

sensitive, that it may serve to detect the weakest electric currents. All parts of the current traversing the elongated parallelogram *p q r o n*, Fig. 417, in the direction of the arrows, act in a similar way upon the needle *a b*, which rotates in a horizontal plane. If *a* be the south end, and *b* the north end, the current will show a tendency at all points to turn the needle in such a manner that *b* shall project beyond the plane of the figure, whilst *a* will retreat behind it. The lower portion of wire, therefore, supports the action of the upper in the same manner as does the current in the portions *p q* and *r o*. A second current of the same force, moving in the same direction round the needle will produce as great an effect as the first, and thus it will be with a third, a fourth, &c. A wire, therefore, wound round a needle, in 100 convolutions, all of which are traversed by the same current, must produce an action of 100 times greater intensity than one of a single convolution; the current must not, however, be propagated laterally from one winding to the other, but must traverse the wire throughout its whole length, being carried actually round the needle. To effect this, we take a copper wire from 15 to 20 metres in length, and closely twined round with silk, which is then wound upon a wooden or metallic frame. The two extremities of the wires of the multiplicator must remain free, so that they may be brought into contact with the poles of the galvanic circuit. The needle is suspended by a silk untwisted thread, and the whole apparatus protected from currents of air by a glass bell. On making an experiment with this, we place the frame in such a manner that the planes of the circumvolutions shall coincide with the magnetic meridian, when the needle will likewise be in the plane of the circumvolutions while no current is passing, but as soon as this is established the needle will deviate in proportion to the intensity of the current.

FIG. 417.



Nobili has made a multiplicator infinitely more delicate than the one we have been considering, by making use of two needles with opposite poles, instead of one needle, as seen in Fig. 418, and still better in Fig. 419. In a system of needles of this kind, the directing force of the earth's magnetism is very inconsiderable, it

FIG. 418.

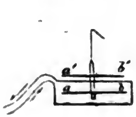
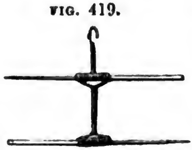


FIG. 419.



being only the difference of the forces with which the terrestrial magnetism strives to direct each needle. If both needles were absolutely equal, and possessed a perfectly equal amount of magnetism, the directing force exercised by the earth upon this system would be null. But one of the needles is suspended within, and the other over the coils of wire, both will therefore be turned towards the same side by the current. An apparatus of this kind is extremely delicate.

FIG. 420.

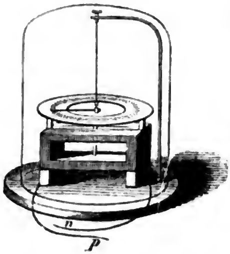
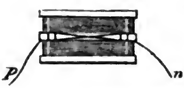


FIG. 421.



To connect the wires in a secure manner, we must either pass both through a perfectly straight blade of straw, or secure them to a very thin wire, as seen in Fig. 419.

The upper needle moves in a circle divided into 360 degrees. The line connecting 0 and 180° is marked upon the magnetic meridian; when there is no current passing through the convolutions the needle points to 0°. The deviation of the needle increases with the increasing force of the current; this force is not, however, proportional to the angle of deviation.

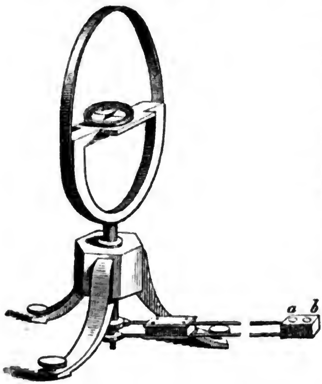
The direction of the deviation of the needle determines the direction of the current.

Fig. 420 represents a complete galvonometer, and 421 exhibits the frame with the coils of the wire as seen from above.

The Tangent Compass.—When we have to do with stronger currents, it is not necessary to use an astatic needle, or to wind the wire so many times round the needle; we are consequently enabled to construct instruments in which the angle of deviation stands in a simple relation to the force of the current. The most simple and useful apparatus for measuring powerful currents is the so-called tangent compass represented at Fig. 422. The current is conducted by a circularly formed vertical copper strip round the needle, which is in the middle of the circle, compared with whose diameter it is very small. The current is conducted through a hollow copper cylinder, from which it passes into the circular band, while the other end of the copper ring is in connection with a copper rod passing through the centre of the copper tube, without being in contact with it. Thus the

current may rise through the hollow copper cylinder, and pass over to the copper ring, traversing its whole length, and returning again through the copper rod, which is insulated in the middle of the cylinder.

FIG. 422.



The apparatus is so placed, that the copper ring lies in the plane of the magnetic meridian, the needle naturally being in this case in the vertical plane of the ring, and pointing to the 0 of the graduated division; as soon, however, as a galvanic current passes through the copper ring, the needle is made to deviate, and the force of the current will be proportional to the trigonometrical tangent of the angle of deviation, hence the name of the instrument.

Force of the galvanic circuit.—The agent which produces the phenomena of galvanism is nothing more than the electricity generated in the electrifying machine and in the electrophorus, only here the electricity is in motion, and there it is at rest; the one presents us with phenomena of motion, the other those of pressure; the one affording us an abundant, the other a comparatively poor supply of electricity.

We may, perhaps, make the true relation of the matter clearer by an illustration. Thus we may compare the electrifying machine to a well, which yields water but sparingly, but lies high on a hill. The water may be collected in a narrow conducting pipe continued into the valley and closed below. The walls of this tube have naturally to sustain a great pressure, especially at the lower end, although the mass of water in the tube may be small. At the lower end of the tube there is an opening closed by a valve, which is pressed against the aperture by a spring or a weight. The more, however, the column of water rises in the tube the stronger will be the pressure; and when the external counter pressure no longer suffices to afford resistance, the valve will be opened, and the water will rush violently forth, at the same time, however, the level of the water in the tube will rapidly sink; the external

pressure will again acquire a preponderating force and close the aperture. By degrees the tube will be refilled, and after a time the water will rise so high, that the valve will be again opened.

In the electrifying machine the conductor is the vessel, or conducting pipe, in which the electricity is accumulated. If we bring a conductor, as the knuckle of the finger to the one end of the conductor, the greatest accumulation of electricity will take place; the electricity will have a tendency to pass to the finger; but the layer of air between the conductor and the hand representing the weight which holds the valve down, will hinder its passage. It is only when the electricity on the conductor has accumulated to a certain amount that the resistance is overcome, the layer of air broken through and the conductor partly discharged. On bringing the finger still nearer to the conductor, the resistance opposed to the passage of the electricity is diminished, which again corresponds to the abatement of the pressure that keeps the valve of the conducting pipe closed.

If the opening at the lower end of the conducting tube were not shut by the valve, the water would flow out in the same proportion as that supplied by the spring, and the accumulation of the water together with the pressure sustained by the walls would cease. As, however, the spring yields only a small quantity of water, very little will flow from the aperture, and the water which was able to bear so great a pressure when accumulated in the tube, can scarcely produce any perceptible mechanical effect when it is suffered to flow freely out.

The case of the conductor of the machine being brought in conducting communication with the earth or the rubber, corresponds to the free discharge of water from a scantily supplied spring. All tension, or accumulation of electricity on the conductor ceases; the thinnest wire being then able to draw off all the electricity from the conductor; while the freely discharging electricity scarcely gives the slightest evidence of those powerful actions observed in galvanic apparatus.

A galvanic apparatus is like a very copious spring having an inconsiderable fall, and whose water is freely discharged in wide channels. The whole mass of the water exercises but a trifling pressure on the walls; but it is capable of producing mechanical effects, moving wheels, &c.

If a large Leyden jar be discharged by a thin wire, the latter

will, as we have already seen, become red hot, owing to the quantity of electricity passed through it. The action, however, is only momentary, as all the electricity accumulated in the jar by the continued turning of the machine passes in a moment through the thin wire. The case is totally different when we unite by a thin short wire both poles of a galvanic apparatus with large plates. The wire will become red hot even when it is far thicker than the wire heated by the discharge of the Leyden jar: but here the heating is not momentary, but continues as long as the current passes through the wire; at every moment, therefore, the galvanic apparatus yields incomparably more electricity than can be accumulated in the Leyden jar by a continued turning of the machine.

Let us now proceed to examine the circumstances on which depends the quantity of electricity which can be engendered by a galvanic apparatus.

When two metals are brought into contact, if only at a few points, we at once obtain an abundant supply of electricity. We have already seen that we cannot form a galvanic apparatus without such bodies as belong to the series of tension. Galvanic circuits are constructed of metals and fluids; the latter, however, are not good conductors of electricity, and rank in this respect far below metals. The moist layers intervening between the metal plates of the voltaic pile are not able in a given time to give a passage to all the electricity which in the same period of time may possibly be engendered by the electromotor force of the pile. It will of course be understood that the quantity of the electricity which can circulate in such an apparatus depends upon the diagonal section of the moist layers; now as the diagonal section of the moist conductor in the voltaic pile depends upon the size of the double plates, we may by increasing the size of the latter, augment the quantity of the electricity. We shall subsequently learn by experimental proofs to test the correctness of this view.

With the increase of the plates in the voltaic pile, the surfaces of contact between the copper and zinc also increase; that the increased quantity of the electric current is not occasioned by this circumstance is, however, proved by the fact that the apparatus delineated in Figs. 401, 402, and 404, which have a large diagonal fluid surface intervening between the copper and zinc, yield a considerable quantity of electricity, although the two

ls are only brought into contact at a proportionally small ce, namely, where the copper wire is soldered to the zinc der or plate.

erything, therefore, which promotes the passage of elecy through the fluid conductor effects an immediate increase of quantity engendered. The shorter the course is which the ricity must traverse in passing through the fluid, and, consetly, the thinner the fluid layer between the metal plates, the ter will be the quantity of electricity that can circulate in the ratus. Thus, the greater the conducting power of the fluid, and closer the metal plates approximate to each other in the fluid, greater will be the electric quantity of the current.

t us now inquire into the influence exercised by the number ie double plates upon the galvanic current. If we suppose a t disc or layer to be placed between a zinc and a copper , and the metals united by a copper wire, we shall have a d simple galvanic circuit. The resistance to be opposed by current in the moist conductor is incomparably greater than resistance opposed by the wire to the circulation of the current; apparatus yielding far more electricity than the moist conor can transmit. If we double the number of elements, ecting the uppermost copper plate by a copper wire with the st zinc plate, we shall have a circuit of two elements. The tion here arises, as to whether by this arrangement a larger itity of electricity can be made to circulate than in the above idered simple circuit?

 the simple circuit, the quantity of the circulating electricity mited by the resistance of the moist conductor; now, this tance is doubled by the second moist layer; but then, on the r hand, the tension urging the passage of the electric current become twice as great, and, consequently, an equal quantity of ricity will circulate in both cases. The increase of the number ouble plates does not tend to augment the quantity of the ilating electricity when the circuit is perfectly closed, since, in case, it is quite immaterial whether we use one or many pairs lates. In an imperfectly closed circuit, however, that is, where d conductor has been made to complete the circuit, many s must be made use of, as a greater degree of electric tension ecessary to force a passage, as it were, through the bad luctor. The intensity of the galvanic current is proportional e number of the double plates.

Ohm's law.—The above indicated relations of the force of the current with reference to the elements of the circuit have been reduced by *Ohm* to strict mathematical formulæ. By means of the law named after him, (of which we shall treat presently), a secure basis was first given to the investigations made on the force of the electric current.

In order that an electric current may pass through a conductor, it is indubitably necessary that the electricity should have an unequal degree of tension at different parts of the conductor. If, for instance, we touch the conductor of an electrifying machine with a wire, the electricity will be propelled through the latter, solely on account of the strong tension of the electricity, which drives it through the wire to the conductor, there being a greater accumulation of electricity at the end of the wire in contact with the conductor than at the opposite end; thus, on connecting together by means of a wire, two similar conductors equally strongly charged with electricity, no current will be formed.

When the *Voltaic* pile is insulated, the opposite electricities at the poles will be in a state of tension, and this condition cannot possibly entirely cease on connecting the two poles by a conductor, since no + electricity can flow from the + pole if there be not here a greater accumulation of the same kind of electricity; a certain tension, like a certain pressure, as it were, is necessary to occasion a motion, by which the resistances may be overcome in the conductor through which the current is to pass.

The quantity of electricity passing through a conductor depends essentially upon two circumstances; first, on the resistance to be overcome in the conductor; and next, on the tension or pressure urging the electricity through the conductor; it will now be easily seen, that the quantity of electricity passing in a given time through some specified conductor, must stand in an inverse relation to the resistance in the conductor, and in a dried relation to the electric tension urging the current through the conductor. The tension is here to a certain extent the accelerating force.

The quantity of electricity passing through a conductor, that is, the force of the current, may be expressed by $\frac{E}{L}$, if E designate the electric tension engendered by the current, and L the resistance to be overcome in the conductor.

Let us here consider the current of one simple closed voltaic element. Let e be the tension occasioned by the current, λ the

resistance in the circuit itself, and l that in the wire closing the circuit; then the force of the current $p = \frac{e}{\lambda + l}$.

If we had combined n such elements into a column, the electric tension setting in motion the current would be $n\,e$; but the resistance in the circuit being increased in an equal proportion, as it has to be overcome not only in one element, but in n elements, the resistance in the conductor will be now $n\,\lambda$. If now the arc closing the circle is the same as in the simple circuit, we have for the force of the current $p^1 = \frac{n\,e}{n\,\lambda + l}$.

If l were very small in comparison with λ, the above given value of p would be nearly $\frac{e}{\lambda}$, but the value of p^1 would be $\frac{n\,e}{n\,\lambda}$, consequently also $= \frac{e}{\lambda}$: if, therefore, the resistance in the arc closing the circuit be small in comparison with the resistance of one single element, the increase of the elements will afford no advantage. On the other hand, an increase of the elements will occasion an increase in the force of the current, if l be very large; that is, if there be a considerable resistance to be overcome in the arc closing the circuit.

We will now consider the influence exercised on a simple circuit, by an increase of its surface. The force of the current for a single element was designated above as $p = \frac{e}{\lambda + l}$; if now the surface of the voltaic elements be increased n times, without altering anything else, the only result will be to make the resistance in the circuit itself n times smaller, owing to the diagonal section of the fluid, through which the current must pass, becoming n times greater; instead, therefore, of the resistance λ, we shall now have $\frac{\lambda}{n}$, and, consequently, the force of the current p'' will now be,

$$p'' = \frac{e}{\frac{\lambda}{n} + l}$$

or what is the same thing,

$$p'' = \frac{n\,e}{\lambda + n\,l}.$$

If l, that is to say, the resistance in the arc closing the circuit, were null, the force of the current would be proportional to the superfices of the electric element; and this is very nearly the case when l is extremely small; an increase of surface produces, therefore, an increase in the force of the current, if the resistance in the closing arc be small in proportion to the resistance in the circuit itself.

The values for the resistances in the circuit itself, and in the closing arc, must, as we shall presently see, be referred to the same unit.

These laws are fully confirmed by experiment.

In order to show that the force of the current stands in an inverse relation to the length of the closing arc, we have merely to complete the circuit of a galvanic element (for instance, one of *Becquerel's* elements) by a tangential compass, and then insert, according to the series, pieces of wire of different length, noting each time the corresponding deviation.

A series of experiments of this kind gave the following results:

Length of the copper wires inserted.	Deviation observed.	Tangents of the angles of deviation.
0 metre.	62° 00′	1,880
5	40 20	0,849
10	28 30	0,543
40	9 45	0,172
70	6 00	0,105
100	4 15	0,074

We observe here, no regularity in the decrease of the intensity of the current on lengthening the inserted wire; but when we consider that this wire is not the only resistance to the current, and that in the electromotor apparatus itself, and in the different parts of the compass through which the current passes, a resistance has to be overcome, which we will designate as the *resistance of the element*, it will be evident that this last named resistance may be estimated as equal to the resistance of a copper wire of the same thickness as the one inserted, and of the unknown length x; the following, therefore, are actually the corresponding lengths of the circuit, and of the angles of deviation.

Length of the chain.	Deviation observed.	Tangents of the angle of deviation.
x	62° 00′	1,880
x + 5	40 20	0,849
x + 10	28 30	0,543
x + 40	9 45	0,172
x + 70	6 00	0,105
x + 100	4 15	0,074

If now the force of the hydro-electric currents is actually inversely as the length of the circuit, the numbers of the first column must be inversely as the numbers of the last, and consequently, $x : x + 5 = 0{,}849 : 1{,}880$, whence it follows that $x = 4{,}11$. If, in the same manner, we compare the first observation with all those succeeding it, we shall always obtain the same value for x; and, indeed, the values thus computed for x are very nearly equal to each other: we find, for instance, besides the value already computed, 4,06, 4,03, 4,14, and 4,09 metres. The mean of which is 4,08.

The resistance of the element is, therefore, equal to the resistance of a copper wire, 4,08 metres in length, and of the same thickness as the one inserted. If we make this length our standard, we may easily, by aid of the general law, that the force of the current is inversely as the length of the circuit, compute the deviations that will be obtained, and then compare them with those directly observed, as has been done in the following table.

Length of the circuit.	The computed deviation.	The deviation actually observed.	Difference.
4,08 metres	62° 00′	62° 00′	
9,08	40 18	40 20	+ 2
14,08	28 41	28 30	— 11
44,08	9 56	9 45	— 11
74,08	5 57	6 00	+ 3
104,08	4 14	4 15	+ 1

Such an accordance between the results of observation, and those derived from a general law, leave no doubt as to the correctness of that law.

In order to show that in a perfectly closed circuit, that is, where the resistance in the conductor is very inconsiderable, the number of the elements does not increase the force of the current in the closing arc, we must successively complete a circuit, composed of 1, 2, 3, or 4 elements, through the tangential compass, and then observe the corresponding deviation. A series of experiments of this kind, gave the following results:

Number of elements.	Deviation observed.
1	69^0
2	66,5
3	67,5
4	67
5	68
6	64.

We see here, that the force of the current remains almost entirely unchanged, not increasing with the addition of the elements. The reason of its not remaining wholly unchanged is, that the individual elements are not perfectly equal.

Where, however, there is a considerable resistance to be overcome, the force of the current is certainly increased with the number of the elements. Six elements, closed by the tangential compass, yielded a deviation of 39^0 after the insertion of a wire 40 metres in length.

One element, closed in the tangential compass by the same wire, measuring 40 feet in length, only showed a deviation of 11^0.

Capacity of metals for conducting electric currents, or the conductibility of metals.—In the experiments given, (at page 404), pieces of wire, varying in length, were inserted in the closing arc of the circuit, and the relation of the force of the current to the length of the closing wire was thus obtained. If now we insert into the closing arc wires of equal length, but of unequal thickness, composed of the same metal, and still observe the corresponding deviations of the needle of the tangential compass, we shall ascertain from these experiments the relation that the force of the current bears to the thickness of the wires; and here we find, *that the force of the current is proportional to the transverse section of the wires;* or in other words, *that two wires composed of the same metal will exercise an equal resistance, if their lengths are inversely as their transverse sections.*

In order to compare the conductibility of different metals,

no method is simpler, or more certain, than to conduct the current of a sufficiently powerful element through a tangential compass, to insert wires of different metals in the closing arc, and to observe the corresponding deviations.

The following are the numbers expressing the capacity of different metals for conducting electric currents:

Silver	136
Gold	103
Copper	100
Zinc	28
Platinum	22
Iron	17
Mercury	2,6.

That is to say, a copper wire of 100 feet in length offers as great a resistance to an electric current, as equally thick wires of silver, zinc, platinum, iron, &c., which are respectively 136, 28, 22, or 17 feet in length.

The conducting power of fluids is very small in comparison to that of metals: thus, ex. gr., the conducting power of platinum is 2½ million times as great as that of a solution of sulphate of copper; while the conducting power of distilled water is only 0,0025 of the conducting power of a solution of sulphate of copper.

PART IV.

ELECTRO-MAGNETISM.

CHAPTER I.

MAGNETIC ACTIONS OF THE CURRENT.

We have already remarked that the electric current is capable of making the magnetic needle deviate, and it now remains for us, without entering further into these magnetic actions, to pass to the consideration of the applications that have been made of the deviation of the magnetic needle, to ascertain the laws of the force of the current. The following chapter is devoted to the further consideration of the magnetic actions of the electric current.

Magnetization by the galvanic current.—The electric current acts not only on free magnetism, but is likewise capable of separating the still combined magnetic fluids. In order to show the action of the current on soft iron, we need only plunge the wire into iron filings, or strew them over it during the passage of the galvanic current. The iron filings remain hanging to the wire until the current is broken; small steel needles may be converted into permanent magnets by means of the galvanic current; in order, however, to render the current very active, we must make it pass transversely round the needle, as is the case in the arrangement we are about to describe. A copper wire is wound spirally round a glass tube, in which a steel needle is placed (see Fig. 423). If now we let a current pass through the convolutions of the wire, the needle will become permanently magnetic, and it is only necessary that the current should pass through it for the space of a minute to magnetise the needle as perfectly as possible.

FIG. 423.

FIG. 424.

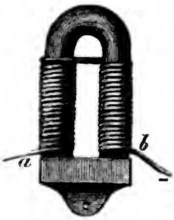
We distinguish right-handed helices as seen in Fig. 423, from left-handed helices as seen in Fig. 424. In the former, the convolu-

s run in the same manner as in a cork-screw, or in an ordinary w.

n right-handed helices the north pole, (that is the south), is at that end of the needle where the + current enters it, le, in the left-handed helix, the north pole is at the extre- y from whence the current passes out. In the figures, the :h pole is designated as *b*, and the south pole as *a*.

Ve may make magnets of soft iron by means of the galvanic ·ent, far surpassing all steel magnets in force. For this pose it is only necessary to encircle a strong horse-shoe soft iron with thick copper wire, in the way represented Fig. 425. The copper wire must be covered with silk, in :r that the current may not pass laterally from one winding

FIG. 425.



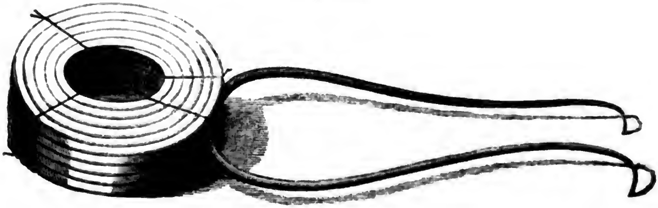
to another, (these windings lying close together), or be transferred to the iron, but traverse the wire in its whole length. The wire is twisted round the curved lines of a horse-shoe, passing round in the same direction, but somewhat inclined to the right; if, therefore, the + current enters at *a*, a north pole will be formed there, and a south pole at *b*. By means of a holder may suspend weights to a magnet of this kind. Thus, a ;net whose diameter is about 6 or 8 centimetres, and whose ›s are about 1 foot or 1,5 feet in length, may sustain a weight from 800 to 1000lbs., provided the wire be thick, and the :ent passing through it be of sufficient strength. As electro- ors for these electro-magnets, simple circuits of a large area are l, or *Groves'* or *Bunsens'* elements; for this purpose, however, the zinc cylinders must be connected together, in the same ıner as all the carbon cylinders or platinum plates. The ;netism vanishes as the current ceases.

ιs we can engender a temporarily powerful magnetism in soft ı by the galvanic current, we are also able to produce steel ;nets of great force by the same means. An arrangement :cially applicable to this purpose is the wire coil constructed by *ıs*, and represented in Fig. 426.

ι copper wire about 25 feet in length, and $\frac{1}{8}$th of an inch in :kness, must be properly encircled with silk, and then wound › a coil, as seen in the figure. The height of the wire coil ›unts to about 1 inch, and the diameter of the inner cavity to

1½ inches. The two extremities of the wires are brought into connection with the poles of a powerful voltaic element when we want to magnetise a steel rod.

FIG. 426.



Whilst a strong current circulates through the wire coils, the steel staff or rod must be inserted into the coil and moved backward and forward, and when the middle part is a second time in the coil, the circuit is opened, and the rod can then be taken out perfectly magnetised.

It is best to put a piece of soft iron above and below the steel rod, and, if the rod to be magnetised be of a horse-shoe shape, it should be provided with a holder during the operation.

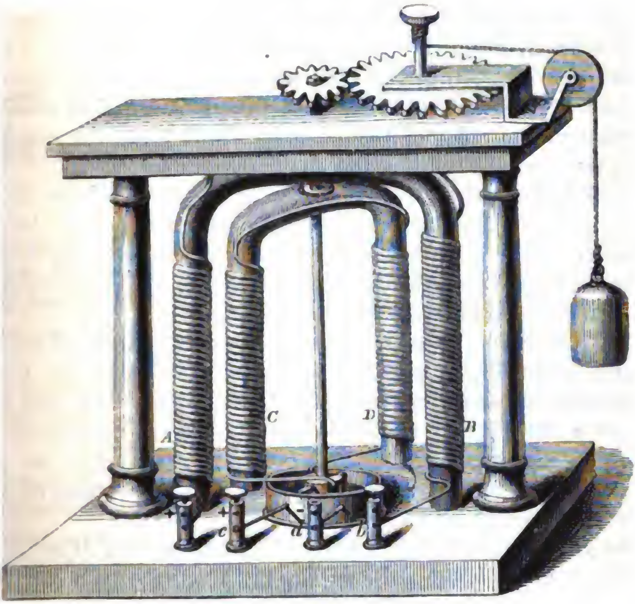
Application of the galvanic current as a moving force.—The powerful magnetic actions which the electric current is capable of producing, have led to the idea of applying them as a moving power. Fig. 427 shows an apparatus which is well adapted to exhibit the manner in which a continuous motion may be produced by the magnetising action of the galvanic current.

A B is a piece of soft iron curved into the form of a horse-shoe, and fixed to a stand, being encircled by a copper wire in the manner indicated in the electro-magnet in Fig. 425. The one end of the wire goes to the brass column *a*, the other to *b*, the poles of a powerful galvanic element are attached at *a* and *b*, and the iron *A B* is thus converted into a magnet.

Within the horse-shoe *A B*, a similar smaller one *C D* is introduced, which rotates about a vertical axis. This iron *C D* is likewise encircled by a copper wire in the manner indicated, the two ends of the wire being plunged into a wooden ring-shaped channel filled with mercury. This channel is divided into two parts by means of a wooden or ivory partition, the one part being in communication by means of a copper wire with the brass column *c*, and the other with the brass column *d*. (The two

oles of a simple circuit are attached at *c* and *d*). The two artitions must now be filled with mercury to such a height that ie level may project beyond the partition walls, although not so

FIG. 427.



to pass from one space to the other, which may easily happen, ring to the mercury forming a convex drop, as it were, in each vision. The two ends of the electro-magnet *C D* penetrate fficiently far into the vessel so as to dip into the mercury either side of the partition wall, but in such a manner as admit of their passing freely over it during the rotation of the ectro-magnet *C D*. In the position of the electro-magnet *D* represented in Fig. 427, supposing the + pole of a werful galvanic element to be connected at *c*, and its — le at *d*, the + current will pass from *c* to the left division the channel, from whence it will go through the copper wire und the moving horse-shoe from *D* to *C*, then from *C* into the ht division of the channel, and from thence to *d*. In this sition the pole *C* will be attracted by *A*, and *D* by *B*, by which otatory motion of the electro-magnet *C D* will be induced. But

now when *C* reaches *A*, and *D* reaches *B*, the two ends of the wire of the inner electro-magnet will pass over the partition wall; the current that makes *C D* magnetic will be interrupted for a moment; as soon, however, as the ends of the wires have passed from one division into the other, the current will go in an opposite direction through the copper wire encircling *C D*, the pole *C* will then be repelled by *A*, and *D* by *B*, whilst *C* and *B* and *D* and *A* will attract each other, thus the rotation of the inner electro-magnet will be continued until *C* comes to *B*, and *D* to *A*, and by another inversion of the poles of the inner electro-magnet, the rotation of the latter will be continued in an opposite direction.

A notched wheel is secured to the rotatory axis of the inner electro-magnet, and connected with a second wheel of larger diameter. Around the axis of the latter a string is wound, which passes over a pulley, and supports a hanging weight that is lifted by the rotation of the inner electro-magnet.

This apparatus is merely an improvement upon *Ritchie's* rotation apparatus, in which a steel magnet supplies the place of the external electro-magnet, whilst the rotating iron has the form of a straight rod surrounded by a wire, the extremities of which are immersed in a channel filled with mercury, as in our apparatus, the rotation being maintained by the inversion of the poles succeeding every semi-revolution.

The attempts made by *Jacobi* in Petersburg, and *Wagner* in Frankfort, to apply the galvanic current practically as a moving power, have not hitherto afforded the desired results.

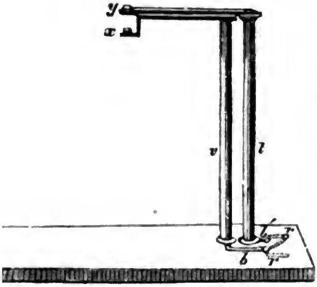
Another practical application of the magnetization of soft iron by galvanic currents has been made use of in the *Electric Telegraph*, the arrangement of which is essentially as follows. If the two extremities of a wire encircling a U-shaped piece of soft iron be made so long as to pass many miles to some distant place, at which there is a galvanic circuit, we may, by alternately closing and opening this circuit with the wire ends, communicate magnetism to, or remove it from the distant iron; and thus we may, consequently, cause the electro-magnet alternately to attract, and again to repel an armature, the motion of which is by means of a tooth of the wheel conveyed to the hand of a disc, round the margin of which the letters of the alphabet are marked. If the hand be properly placed, it will move to *A* on the first closing of the circuit, to *B* on the succeeding opening, and to *C* on a second closing, and so forth. We may thus bring the hand to any number of letters

er the corresponding number of openings and closings of the cuit, and, consequently, designate words and sentences, no less n single letters. It would carry us beyond our limits to enter re fully into the arrangement of this apparatus.

Direction of currents by the influence of terrestrial magnetism.— ce the current exercises an influence on magnets, we cannot ıbt that a like action is conversely transferred by magnets to current, and that they are able to direct it in different ways. ıongst all these converse phenomena, the most interesting is t exercised by terrestrial magnetism on currents, and attempts l frequently been made to establish moving currents, which, en left to themselves, might exhibit all the phenomena of needle; these experiments, however, all failed, owing to necessary mobility not being given to the currents. At gth all these difficulties were overcome by an ingenious trivance of *Ampère*, which admits of being applied to all rents.

Fig. 428 represents two vertical brass columns secured to a wooden stand, and having at the top two horizontal arms, terminating in the mercury cups x and y, of which the one central point is placed vertically below the other. Where the horizontal arms appear to be in contact, they are separated by insulating substances; when, therefore, the feet of the columns are brought in nection with both poles of the circuit, one of the electric ds will reach the cup x, and the other the cup y. One these cups may be named the *positive*, and the other the *ıtive.*

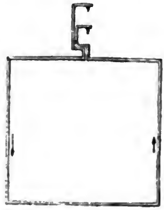
FIG. 428.



copper wire, curved in the manner shown in Figs. 429 and , is suspended to the cups x and y. The wire ends are separ d by an insulated substance where they appear to be in tact; they are curved at the top, and provided with steel ıts which are plunged into the cups x and y (Fig. 428). The point penetrates to the bottom of the cup, and rests upon nall glass plate, while the other point is only just immersed

FIG. 429.

FIG. 430.



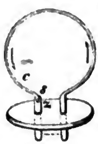
in the mercury. By this suspension the wire becomes very moveable.

On suffering a current to pass, the wire, after making several oscillations, will place itself in a definite position, to which it will invariably return if removed from it.

If we turn the current, bringing the column which was previously in connection with the + pole of the circuit into contact with the — pole, and *vice versâ,* the wire will describe half a revolution round its vertical axis of rotation before it will recover its equilibrium. In both positions of equilibrium, the circle stands in such a manner that its plane makes a right angle with that of the magnetic meridian. *Stable equilibrium will be established when the positive current passes from east to west in the lower half of the circle.*

Very weak currents are even directed by terrestrial magnetism, and on this principle rests the construction of the apparatus in Fig. 431. In a piece of cork, swimming in acidulated water, we secure a piece of zinc and a piece of copper, which reach into the fluid, and are connected at the top by a circular copper wire. When placed upon the water, a current will be found which passes from the zinc in the water to the copper, and then through the wire following the direction indicated by the arrows. This current is sufficiently strong to be directed by terrestrial magnetism, and will therefore so much the more be directed, attracted and repelled by a magnet.

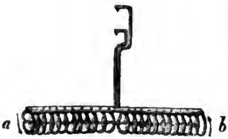
FIG. 431.



As a closed circular current, revolving round a vertical axis, places itself at right angles with the magnetic meridian, it follows that a combination of parallel circles which are traversed in the same direction, must range themselves in the like manner. Thus

the wire helix seen in Fig. 432, when suspended by *Ampère's* stand, and when traversed by a current, must place itself in such a manner that its axis shall be in the line of the direction of the needle of declination.

FIG. 432.



It not only follows from this, that the needle of declination may be thus imitated by a wire helix, but also that the south pole, that is, the one directed to the north, is the one on the right side of which lies the ascending current, if we look at it from its present side. If we look at the wire from *a*, we have the ascending current to the right, and the descending one to the left; but if we consider the wire helix in the direction of *b*, we shall have the ascending current to our left; *a* consequently is the south pole, and must turn to the north. In like manner, we may say that if a needle of declination be placed in a position of equilibrium, the lower current will go from east to west.

The board, to which the different windings of the wire helix (Fig. 432) are secured, is made of a non-conducting substance.

If we bring a magnetic bar to the helices we have been considering, we may observe phenomena perfectly similar to those exhibited on bringing a magnetic bar near a needle of declination. In fact all the apparatus hitherto described will, as we may conjecture, be affected by magnetic bars.

Reciprocal action of galvanic currents on each other.—Two parallel currents always exercise an action on each other, which is more or less energetic according to their distance, intensity and length. If we consider the direction of the motion produced, we shall find it to be subjected to the following simple law; *two parallel currents attract each other if they move in the same direction, but repel each other if their directions be opposite.*

The above statement may be proved by the following apparatus: *a b c d e f* is a rectangular figure formed of copper wire, and suspended in the mercury cups *x* and *y*. The current ascends through the column *t*, traverses the wire figure in the direction of the arrows, and descends into the column *v*. The current in the column *t*, follows the same direction as that in the piece of wire *d e*; the same is the case with respect to the current in *b c* and *v*. If we remove the rectangular figure from the position represented in Fig. 433, it will always return to the same, owing to *d e* being attracted by *t*, and *b c* by *v*.

If we put the wire figure in Fig. 433 in the place of that

FIG. 433.

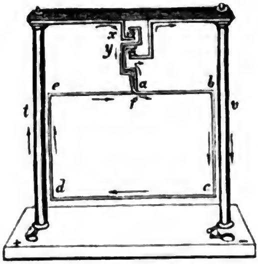
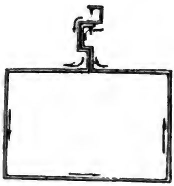


FIG. 434.



suspended in Fig. 431, the current in the wire will have an opposite direction from that in the succeeding column, and we shall observe a repulsion; *parallel opposite currents, therefore, repel each other.*

We call such currents as are not parallel, *cross currents,* whether they lie in the same plane, and their directions intersect each other, or whether they are in different planes, and do not intersect each other. In the first case, the *crossing* point is the point in which they intersect each other; in the second, it is a point of the shortest distance of both currents. *Two cross currents always strive to range themselves parallel to each other, in order to move in the same direction;* or in other words: *attraction takes place between the parts of a current and those which approach the crossing point, and then again, between those going from the crossing point. Repulsion occurs between a current moving towards the crossing point, and another moving away from the same point.*

If, for instance, *a b* and *c d* (Fig. 435) are two currents, whose

FIG. 435.

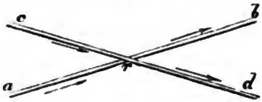
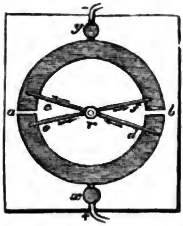


FIG. 436.

FIG. 437.



crossing point is *r*, attraction will take place between the parts *a r* and *c r*, in which the current that passes towards the crossing

point, and between the parts *r b* and *r d,* in which it goes from the crossing point. Repulsion takes place between *a r* and *r d,* and further between *c r* and *r b.*

The apparatus of which a diagonal section is represented in Fig. 436, and an outline in Fig. 437, serve to prove this proposition. Two semi-circular channels, divided by insulated partition walls *a* and *b,* are inserted in a plate of wood. In the middle point rises a spike, to which is attached an easily moving copper needle *c d,* the extremities of which are of iron and dip into the mercury of the channel. Somewhat below this needle there is another, *e f,* the extremities of which are likewise dipped into the mercury, and may be moved by the hand. The current which enters at *x* passes into the one channel, and then through the two needles into the other, and passes out at *y.*

The repulsion is exhibited on placing the needles in the position indicated by Fig. 437, and the attraction on bringing them into such a position, that the angle *e r d* may be less than a right angle.

Ampère's Theory of Magnetism.—The principle of this theory consists in considering each molecule of a magnet surrounded as it were by a current, always circulating about it and returning upon its own course, which may for the sake of simplicity be regarded as circular. We must, therefore, according to this theory, regard every section at right angles to the axis of the magnet to be somewhat similar to what we have attempted to delineate in Fig. 438. Instead of taking into account all the elementary currents of each diagonal section, we may suppose the latter to be encircled by one single current, which is as it were the resultant of all the elementary currents of the diagonal section, and consequently

FIG. 438.

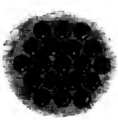
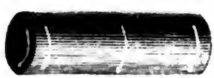


FIG. 439.

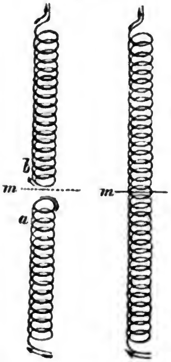


we may regard a magnetic bar as a system of parallelly closed currents, somewhat in the manner shown in Fig. 439.

What we have said here of a magnetic rod applies equally to a magnetic needle, and, in short, to every magnet, let its form be what it may.

Let us suppose a wire helix extending from *m,* Fig. 440, to either side, and traversed by the current in the direction of the

FIG. 440.



arrows; if further we assume this to be cut through at *m*, and the two parts separated, it follows from our definition that there will be a south pole at *a* and a north pole at *b*, for on turning to the pole at *a*, we shall have the ascending current to our right, while on turning to the pole at *b*, we here have it to our left.

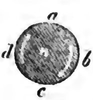
If we cut a wire helix at right angles to its axis, two contrary poles will be formed, exactly as on breaking a magnet.

Further it is clear, that the contrary poles *a* and *b* attract each other, for on looking only at the end circle, we see that the currents are directed parallelly and similarly, and the same is the case with respect to all the other circles. The best way to give an illustration of the attraction and repulsion of the poles in different positions of the magnets with respect to each other, is by drawing arrows upon wooden or pastebord cylinders from 1 to 1,5 foot in length, and from 2 to 3 inches in diameter, as seen in Fig. 439, which represents the direction of the currents; further we may, in like manner, mark on both cylinders the similar poles, designating the north pole as +, for instance, and the south pole as —. By the help of two such models we may easily show how similar poles always repel, and contrary poles attract each other, and in whatever manner we bring them near one another.

According to this hypothesis, the magnetism of the earth also depends upon such currents, moving in the crust of the earth parallel with the magnetic equator.

Rotation of moveable currents and magnets.—Let *a b c d*, Fig. 441, be the horizontal section of a magnet standing in a vertical position, and a vertical current appearing foreshortened at the point *s*, and which we will assume to be ascending, and

FIG. 441.

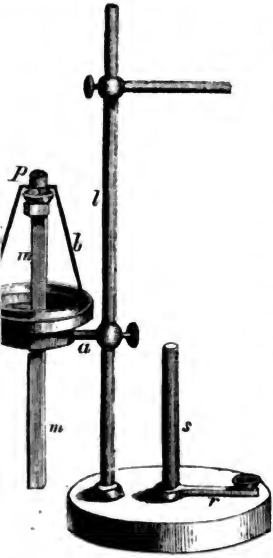


which is capable of rotating round the vertical axis of the magnet; it will then be evident from the above developed principles, that the portion *a b* of the magnetic current will repel the current *s*, while it will be attracted by *b c*, the current *s* must consequently rotate in the direction of the current in the magnet. If the current *s* were descending, the rotatory direction would be reversed; in like manner, of course the inversion of the

agnetic poles will occasion the rotation to assume an inverse rection.

A rotation of this kind may be effected by means of the paratus seen in 442. To a vertical staff *l* is attached a moveable horizontal staff *a*, in such a manner that it may be moved to any height we please, by means of a screw. This horizontal staff is provided with a brass ring, to which is attached a circular wooden channel for holding mercury. In the brass ring there is a cork disc, through the middle of which passes a vertical magnetic bar, having at the top a joint with a steel cup screwed on it. This cup has a fine point in its centre, supporting a copper band *b*, which is curved at either side, in such a manner that its lower ends, with their platinum points, dip into the mercury. In the middle of the copper band is a mercury cup *p*. On the one polar wire of the chain being immersed in the cup *p*, and the other in the channel, the rrent passes through the two arms of the copper band, which en begins to rotate. The action of the magnet on the current the one arm of the band is sustained by the action which the agnet produces on the current in the other arm.

FIG. 442.



We may similarly produce the rotation of a moveable magnet und a fixed current, and the rotation of a moving current round fixed magnet; and the apparatus serving for this purpose ve been constructed in a variety of ways.

CHAPTER II.

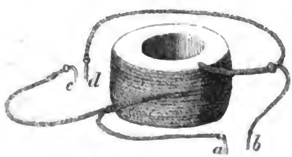
PHENOMENA OF INDUCTION.

An electric current is able to engender like electric currents in another contiguous conductor at the moment of its origin or its cessation, and also by mere approximation or distance.

These phenomena were discovered by *Faraday* in the year 1838, and deserve the greatest attention, both owing to their theoretical importance, and to the numerous facts that can be derived from this principle. These new currents produced in conductors by the distributing action of other currents, are termed *Induction currents.* They might also be called *temporary currents,* as they last but a moment. If we were to name them according to their origin, as has been done in the case of the *thermo-electric* and the *hydro-electric currents* we might give them the appellation of *magneto-electric,* or *electro-electric,* since they are either engendered by magnetism or electricity. We will, however, once for all, abide by the term *Induction currents,* which has also been adopted by the majority of natural philosophers.

Action of an electric current on a conducting circuit within itself.—Two copper wires covered with silk thread are wound upon a reel of wood or metal in the way exhibited in Fig. 443. The one wire runs beside the other without there being any communication between them; if, therefore, we close a galvanic circuit with one wire, while we place its two ends *a* and *b* in connection with its poles, the current will circulate through that wire without passing into the other. In this other wire, however, a current in *an opposite direction* is produced by the inductive action of this current, provided the ends *c* and *d* of this second wire are in connection; which may be effected by means of a multiplicator, on bringing *c* into communication with the end of one of the wires of the latter, and *d* with the end of the other wire. At the moment in which we close the galvanic circuit with the first wire, the deviation of

FIG. 443.



ıe needle of the multiplicator indicates a current in the adjoining ire; supposing the positive current to pass in the main wire ·om *a* to *b*, the multiplicator manifests that there is a current in ıe contiguous wire traversing it in a direction from *d* to *c*.

This current in the adjoining wire is not, however, lasting, for ıe needle of the multiplicator returns immediately to zero on ıe graduated line; as soon as the principal current is interıpted, the needle of the galvanometer turns in the opposite irection, it, therefore, indicates a current passing through the ighbouring wire in the direction from *c* to *d*, consequently, in ıe same direction in which the interrupted current had moved.

An electric current may therefore induce currents in a conguous wire both at the moment of its origin and of its cessation. he current induced by the closing of the circuit has the opposite rection to the one induced by the interruption of the circuit, ıd is in the same direction as the principal current.

In the above adduced experiments, the current in the principal ire induced a current in the other wire both at the moment of its igin and of its cessation; we might, therefore, conjecture that ese actions were produced by some modifications accompanying e beginning and ending of the current. To remove all ubt on the subject, *Faraday* has proved by experiment, that actly the same results are obtained on bringing a conducting re that is traversed by a current, consequently, the wire from ıich the inducing action proceeds nearer to, or further from e wire in which we wish to induce a current.

If therefore we say, that the action of a current on a closed nductor begins, we either understand thereby that the inducing rrent itself begins, or that it is already on its course, and ought near to the closed conductor. In these two cases the tions are precisely similar. If we say that the action of a rrent on a closed conductor stops, it means, that the inducing rrent itself either ceases, or is removed from the closed conıctor.

Currents of induction produce all the actions of ordinary rrents, as, for instance, shocks and sparks. On bringing the ds of the wires *c d* close together, we see a spark pass over, the circuit be closed by the ends *a* and *b* of the inducing wire. we seize the wire end *c* in one hand, and *d* in the other, (the nds must be somewhat moistened for making the experiment), shall feel, on the opening and closing of the principal current a

shock, the violence of which will depend upon the length of the coiled wire.

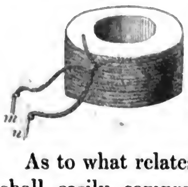
Very violent actions may be produced on the nerves by the above described double spiral apparatus, for if the encircling wire be of considerable length, the intensity of the inductive currents will be incomparably stronger than those of the current yielded by the galvanic circuit commonly used. A simple galvanic circuit, or even a battery of 4, 6, or even 12 pairs gives no shocks by itself, but if we close a circuit of a few or only one pair, with the ends of the inducing wire we shall obtain a powerful shock at this wire.

An induction spiral changes, therefore, in some degree the electric quantity of a current yielded by one or more pairs of large superficies into a current of great intensity; an apparatus of this kind affords, therefore, an excellent means of producing physiological effects, if care be taken alternately to close and open the circuit in rapid succession. Many very ingenious contrivances have been proposed for effecting this purpose.

Action of the windings on each other.—If we close a simple circuit by a short wire, we shall obtain only a faint spark on again opening it, and no shock; but if we use a very long wire instead of the short one, we shall see a much stronger spark on opening the circuit, and if we hold one end of the wire in one hand, and the other in the opposite hand, we shall perceive a shock at the moment of opening the circuit. These actions are very much strengthened by winding the wire as closely as possible, and here it is of course necessary to cover the wire with silk, in order to prevent the current passing laterally from one winding to another.

This action of long spiral wires may be well shown by means of a simple spiral, Fig. 444, it being only necessary to plunge the wire ends *m* and *n* into the mercury cups forming the poles of a galvanic circuit, and on withdrawing the ends of the wires we shall see a brighter spark and feel the shock. On suffering these shocks to pass in rapid succession through the body, violent actions on the nerves may be induced.

FIG. 444.

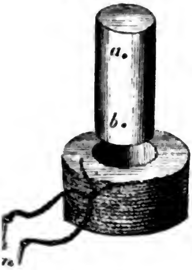


As to what relates to the explanation of these phenomena, we shall easily comprehend that they must stand in a very close relation to the induction phenomena before described. *Faraday*

scribes these effects to an inductive action reciprocally exercised ı each other by the convolutions of one and the same spiral, and ılls this current of induction an *extra-current*. It arises at the ıoment of the opening and closing of the circuit.

Induction of electric currents by magnets.—A metal wire ıcircled with silk must be wound over a wooden or metal rod, ıe inner opening of which is sufficiently large to admit of the ısertion of a magnet. The two ends *m* and *n* of the wire must be ut into communication with the two ends of the multiplicator wire f a galvanometer, sufficiently far removed to prevent the magnet om causing the needle of the instrument to deviate. At the moment ı which the magnet is inserted into the helix, we shall observe deviation of the galvanometer needle, which, however, will soon return to the point 0 of the graduated division, moving away again in an opposite direction on withdrawing the magnet from the helix. The direction of the current indicated by the galvanometer on the approximation of the magnet is opposite to that of the currents, which, according to *Ampère's* theory circulate about the magnet; the current induced in the wire on the removal of the magnet has the same direction as these currents.

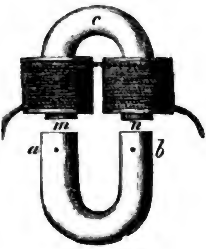
FIG. 445.



By this experiment an action is produced on the closed wire ɔils on the approximation or removal of the magnet; but this ıagnetic action may begin and cease in a different manner; may, for instance, begin at the moment in which the magnetic uids in the iron are decomposed, and cease when it returns to ıe non-magnetic condition. This may be shown in the following ıanner.

In Fig. 446 *a b* is a strong horse-shoe magnet, *m c n* a piece of soft iron, likewise bent in the form of a horse-shoe, and having its limbs enclosed by the coils of one long wire covered with silk. The direction of the coils on both limbs must be such, that on the current passing through the wire, the two limbs may form opposite poles. The two ends of the wire are connected together at a sufficient distance from the iron and the magnet, and a simple magnetic needle, above

FIG. 446.



or below which the wire is conducted, is at once made to deviate by the induced current. If we rapidly bring the magnet *a b* to the limbs *m n*, the needle will indicate the presence of a current, having an opposite direction to that which, according to *Ampère's* theory, circulates round the iron that has now been converted into a magnet. On the removal of the magnet *a b*, the induced current takes the same direction as the one now ceasing in the soft iron.

We may easily show that this current induced in the wire is not the direct action of the magnetic poles of the approximated magnet; for this current attains such intensity, that if even the two ends of the wire are not in perfect contact, but at some little distance from each other, a vivid spark will pass over, as well when the magnet is rapidly approximated, as when it is removed. This electric spark is evidently produced by magnetic actions. On taking one end of the wire in each hand, we experience on the approximation and removal of the magnet a shock, which, provided the magnet be sufficiently powerful, will be like the shock of a small Leyden jar.

Currents may even be induced by terrestrial magnetism. If we hold a rod of soft iron, encircled by a wire helix, in the direction of the needle of inclination, and then suddenly invert it, so that its upper part shall incline downward, and *vice versâ*, a current will be induced in the wire helix.

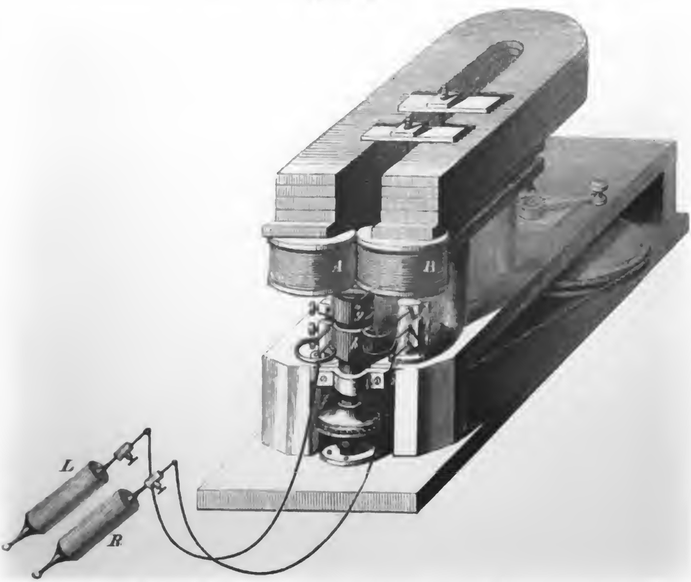
If the inner horse-shoe of the apparatus, seen in Fig. 427, rotate under the circumstances indicated in the experiment adduced, currents must be induced in the windings of the wire on the approximation of the limbs of the inner horse-shoe towards those of the external iron, these currents will be, according to the above developed principles, opposite to those occasioned by the rotation; the currents, induced by rotation, must necessarily weaken the force with which the limbs of the two horse-shoes attract and repel each other; and thus these currents of induction cause the mechanical effect produced by such apparatus of rotation to be much less considerable than one might be led to expect, judging from the force of magnetism that may be imparted to a piece of soft iron by a galvanic current.

Magneto-electric machines of rotation.—If we suppose the ends of the inductive-spirals, which are at the poles of the core of a horse-shoe formed of a piece of soft iron, (as have been considered at page 423) to be in connection with each other, and then that this soft iron revolves rapidly about a vertical axis, so that the pole *m*,

which is immediately above *a*, after half a revolution, stands above *b*, there will then be a current induced in the convolutions of the wire, *m* recedes from *a*, and *n* from *b*; this current will now continue with varying strength, but with unvarying direction during half a revolution, that is, while *m* turns from *a* to *b*, and *n* from *b* to *a*; as soon, however, as the second rotation begins, the direction of the current will change, and will again change after the completion of a whole rotation; if, therefore, the soft iron rotate rapidly with its wire convolutions, the latter will be constantly traversed by alternating currents, passing into each other every time the poles of the soft iron stand over the poles of the magnet. That the direction of the currents actually changes in the way indicated, is easily seen from the rules given concerning the direction of the induced currents, for as *a* and *b* are opposite poles, the removal of *a* must induce a current in the same direction as an approximation towards the pole *b*.

In order to be able conveniently to make experiments on the

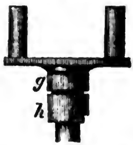
FIG. 447.



currents induced by magnets, machines have been constructed according to the above indicated principles, which bear the name of

magneto-electric machines of rotation. Fig. 447 represents one of these. The inductive spirals, *A* and *B*, are wound round two cylinders of soft iron, secured to the two ends of a horizontal iron plate, the centre of which is on a vertical iron axis, as may be seen in Fig. 448. The manner in which the rotation of this vertical iron axis is effected, is made apparent in Fig. 447, and needs no further explanation. During the rotation the two iron cores pass under the poles of several powerful horse-shoe magnets, laid horizontally over each other, and each iron core of the horse-shoe is thus alternately converted into a north and a south pole.

FIG. 448.



The convolutions around both iron cores are of course formed only by one very long piece of wire. The one end is fastened by means of a screw to an iron ring *g* protected by some insulating substance, solid wood or iron, from contact with the iron axis of rotation, as seen in Fig. 449. The opposite end of the wire is in like manner screwed upon the iron plate which supports two cores; it is, consequently, in contact with the whole iron axis of rotation.

On this iron axis an iron cylinder *h* is immediately secured, which we will at once consider. As the iron ring *g* is in communication with one end of the wire, and the iron cylinder *h* with the other, we may regard *g* and *h* as the ends themselves; the inductive spiral will be closed on bringing *g* and *h* into connecting communication with each other; on this being done the current of induction will circulate in the wire coils, and the whole system be made to rotate. For the sake of simplifying the matter, we will designate the whole rotating system by the name of *Inductor*.

FIG. 449.

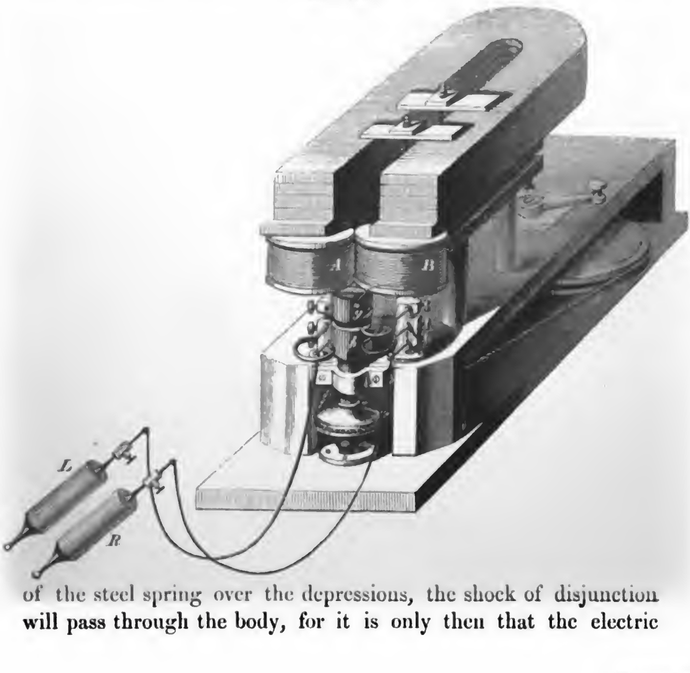
We have still to consider the iron cylinder *h*, which consists of three divisions lying over one another, and of which only the middle one has a perfectly unbroken circumference. At the upper parts are two channel-like depressions diametrically opposite to each other, while at the lower end of *h* a part is cut away, which takes off about half the circumference, as may be clearly seen in our Figure.

On either side of the axis of rotation is a small brass column with several apertures, in which metallic springs may be inserted, and the circuit be thus closed in various ways.

Our Figure represents the machine as it must be arranged, in order to produce powerful physiological actions. In the upper-

most aperture of the column to the right, a spring is screwed on which constantly presses upon the iron ring *g* during the rotation of the inductor; but the steel spring in the next aperture closes upon the upper part of the iron cylinder *h*, and in this manner the circuit is closed; while, as often as the end of the steel wire passes over one of the channel-like depressions, the connection is interrupted. This interruption occurs exactly when the poles of the inductors have been removed from over the magnetic poles. There exists, however, another connection between the iron ring *g* and the cylinder *h*, into which the human body may be brought. A brass spring, constantly pressing upon the middle part of the cylinder *h*, is screwed into the left side of the brass pillar; by which means the small brass pillar to the left is connected with *h*, as *g* is with the pillar to the right. A metallic conductor *L* is in connecting contact with the pillar to the left, and the conductor *R* with the pillar to the right; as often, therefore, as the current there is interrupted by the sliding

FIG. 450.



of the steel spring over the depressions, the shock of disjunction will pass through the body, for it is only then that the electric

current (which hitherto has passed directly from *h* through the steel spring to the right hand pillar) now passes by a circuitous course, first to the left pillar, from this to the conductor *L*, through the human body to *R*, and then finally to the pillar at the right. On turning the machine rapidly, the shocks of disjunction will succeed each other so violently that it will scarcely be possible to endure the effect. If we wish to weaken the intensity of the shocks, it is only necessary to turn the machine more slowly, or to connect both poles of the inducing magnets, by means of an armature of soft iron.

PART V.

THERMO-ELECTRIC CURRENTS AND ANIMAL ELECTRICITY.*

If two metallic bars be so soldered together that they compose a closed circuit of any form we choose to give them, a more or less intense current will be produced as often as the temperature varies at the two places of junction, the current continuing as long as this difference of temperature is maintained.

This may be shown for a special case with the apparatus in Fig. 451. *s s′* is a piece of bismuth, *s c s′* a band of copper soldered on the ends of the bismuth bars; *a b* is a magnetic needle, moveable freely on a point. If the two places of junction have the same temperature as the surrounding air, the apparatus must be so placed that the plane *s c s′* may coincide with the plane of the magnetic meredian, and that, consequently, the needle may stand parallel with the axis and the longer sides of the bismuth bar. As soon now as one of the joining-places, *s*, for instance, is heated, the needle will experience a more or less strongly marked deviation; but if this spot *s* be cooled below the temperature of the surrounding air, we shall observe a deviation in the opposite direction.

FIG. 451.

These deviations of the needle, first to the one side and then to the other, evidently indicate the presence of an electric current, traversing the apparatus in a definite direction, if the spot *s* be warmer than *s′*; but in an opposite one if *s* be cooler than *s′*.

* Professor T. Thomson's "Heat and Electricity," 8vo. 2nd edition, London, 1840.

All metals do not yield the same marked results as bismuth
l copper; and in such cases we must use a system of two
:dles, as seen in Fig. 452, instead of one. The upper band *s c s'*

FIG. 452.

has an opening in the middle, to admit of the passage of the connecting piece between the two needles, while the point, however, on which the system of the two needles plays, passes to the upper needle.

It is not essential to have an especial apparatus (as seen in Fig. 452) for making the fundamental experiments on thermo-electric currents, since we may use any delicately suspended compass needle
tined for this purpose, somewhat like that delineated in Fig. 453.

FIG. 453.

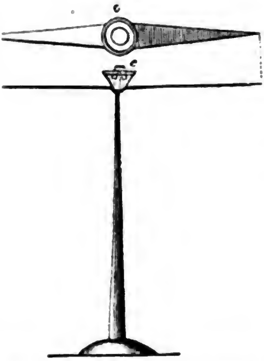
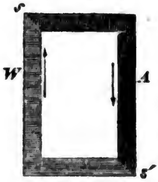


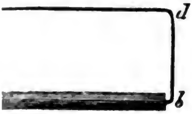
FIG. 454.



Here we have an elongated parallelogram, Fig. 454, as the thermo-electric element, composed of bismuth and antimony. In our figure the lightly shaded half designates the former, and the darkly shaded half the latter constituent. The two metals are soldered together at *s* and *s'*. In order to make this experiment, we must
:fully warm, over a small spirit lamp, the one soldered junction,
then hold one of the longer sides of the figure over the mag-
c needle, which must then be in its usual position. We must
ark here, that Fig. 454 is delineated on a somewhat smaller
e than 453; since the parallelogram of bismuth and antimony
ht to be so large, that each of its longer sides may be at least
qual length with the magnetic needle.

imple thermo-electric circuits are often made in the manner
·esented in Fig. 455; *a b* is a small bar of antimony or bis-

FIG. 455.



muth, at both sides of which a copper wire *a e d c* is soldered. To make this experiment, we must warm the one soldered joining either at *a* or *b*, and hold the piece of wire *e d* over the needle.

he investigations that have been made as to the mutual rela-

tion of different metals, with respect to the excitement of thermo-electric currents, have shown that the metals admit of being ranged in one series, which has this property, that, on forming a circuit of every two metals, and heating the place of contact of the two, the + current at this spot will pass from the metal standing immediately below it to the one above.

Antimony	Tin
Arsenic	Silver
Iron	Manganese
Zinc	Cobalt
Gold	Palladium
Copper	Platinum
Brass	Nickel
Rhodium	Mercury
Lead	Bismuth

Thus, in the apparatus Fig. 451, the current will pass in the direction from *s* over *c* to *s'*, and then back to *s* on heating the soldered part at *s*. At this point *s*, therefore, the next body standing higher, viz. copper, is positive with respect to the lower one, bismuth. In the parallelogram, Fig. 454, the positive current circulates in the direction of the arrow, if the spot at *s* is warmer.

Thermo-electric Piles.—As in the case of Volta's piles, so we may also here combine many thermo-electric elements to form thermo-electric piles, capable of giving a current if the soldered parts 1, 3, 5, &c., be warmed, while the intervening points remain cold.

Thermo-electric piles of this kind may serve, in connection with multiplicators, to make the slightest difference of temperature manifest. Amongst all those constructed for this purpose, the apparatus proposed by Mobile is undeniably the most ingenious and the most sensitive. Fig. 456 represents an apparatus of this kind. It is composed of from 25 to 30 very fine needles of bismuth and antimony, which are about 4 or 5 centimetres in length. They are so soldered together, see Fig. 457, that all the even soldered joinings are on one side, and the odd joinings on the other. The whole forms a small, compact, solid bundle, owing to the insulating substances with which the intervals between the several rods are filled; for they must of course not be in contact, excepting at

FIG. 456.

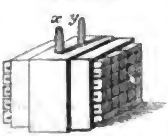


FIG. 457.

the soldered joinings. One of the two half elements in which the circuit terminates is in connection with the peg x, and the other with the peg y; x and y form in this manner the two poles of the pile, and are brought into communication with the ends of the multiplicator wire.

If the soldered points on the one side experience the slightest elevation of temperature, the multiplicator needle will at once deviate from the magnetic meridian.

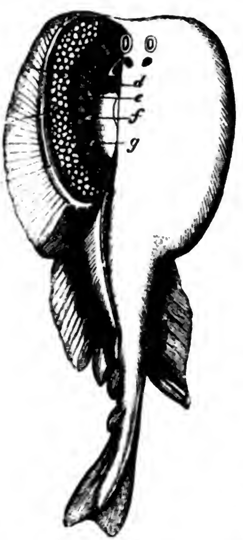
Animal Electricity.—It has been long known that there are fishes capable of imparting electric shocks; among which the most remarkable are the torpedo and the electric eel. The former is met with in the Mediterranean and in the Atlantic Ocean, and the latter only in the inland pools of South America.

When the torpedo is out of water, we experience a shock on touching any part of its skin, either with the finger or the whole hand.

We may in like manner receive a shock on touching the fish with a good conductor, as that of a metal rod several feet in length.

The shock is prevented by every bad conductor, and we may consequently seize the animal with impunity by means of a glass or resin hook.

FIG. 458.



The back of the animal is positively, and the abdomen negatively electric; the electric current passing through a conducting wire, and connecting the back and abdomen, produces all the actions of electric currents, although only in a modified form.

The organ in which the electricity is developed has, in the different electric fishes, essentially the same texture and appearance, although its form, size, and arrangement differ. We will now attempt to give an idea of the organ of the torpedo,—the fish which has been most accurately examined.

Fig. 458 represents a torpedo seen from above, opened at the side to show the electric organ. This

passes anteriorly close to the fore part of the head, its upper surface touching the skin of the back by means of a fibrous membrane, and the lower surface touching that of the abdomen; its external surface rests upon the muscle of the lateral fin, and the inner one at the principal muscle of the head and the anterior part of the trunk. Seen from above or below, the electric organ exhibits polygonal, or roundish divisions (Fig. 459); but from a lateral point of view it exhibits parallel stripes or bands, as seen in Fig. 460. The whole organ consists of a number of polygonal or roundish columns, the axis of which runs in a direction from the abdomen to the back. The marginal edge of each column forms a somewhat thick tendonous membrane, appearing to answer the same purpose as the glass plates between which the galvanic pile is built up. Each column consists of a number of fine teniæ, which are either plain, or curved, and are separated by very adhesive mucous layers; thus these columns afford a striking resemblance in their construction to a galvanic pile.

FIG. 459.

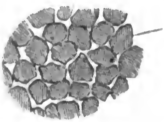
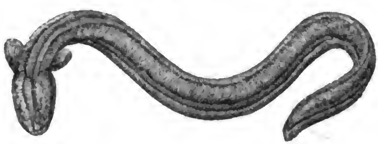


FIG. 460.

There are generally found to be from 400 to 500 such columns or piles on either side of a torpedo.

In the electric eel (Fig. 461) the electric organ is situated in its tail. In this animal the anus lies so far forward, that the tail of the gymnotus is nearly 4½ times as long as the body and head combined; and here the electric organ extends almost the whole length of the tail on either side of and under it, so that the electric apparatus of the animal has a very great extension, owing to which the electric eel is able to impart shocks of extreme violence.

FIG. 461.



In the gymnotus, the columns forming the electric organ do not lie vertically, as in the torpedo, but extend in the direction of the tail; so that the discs of which they are composed stand vertically. Hence it comes, that in the electric eel the positive current goes in

the direction of the head towards the tail; consequently not like the torpedo, where the current passes from the back to the abdomen.

Electric currents, not occasioned by especial electric organs, have been observed in the animal organism. *Nobili* has found, that on touching with the one wire end of a multiplicator the head of a living or dead frog, and its feet with the other wire, a current will pass from the head to the feet. In like manner, a current may be observed on making an incision into the muscle of any animal, and connecting the exterior surface of the muscle with the cut surface by means of the multiplicator.

SECTION VII.

OF HEAT.*

CHAPTER I.

EXPANSION.

Our capacity of feeling enables us to discriminate between the different conditions which we term *hot, warm, cold,* &c., in various bodies. If a body that we call cold become warm, and hot, it will increase in volume, or be expanded.

The unknown cause producing this expansion of bodies, and which at the same time occasions the different above-mentioned impressions on our capability of feeling, is termed *heat*.

Heat not only effects an expansion in bodies, but is likewise able to alter their aggregate conditions, fusing solid, and evaporizing fluid bodies. We will now proceed to the consideration of the laws of these phenomena.

The Thermometer.—Since all bodies are expanded by heat, and as the volume of a body depends upon the degree of heat it possesses, the expansion of a body may serve to measure the degree of its heat; and this degree of heat we term *temperature*, and the instrument used to define it, a *thermometer*.

Fig. 462 represents a mercurial thermometer; the bulb is filled with mercury; this fluid rises in the tube to a definite height, dependant on the temperature. If the bulb be warmed, the volume of the mercury will be increased, and it will rise in the tube, and we say the temperature has increased. If the bulb be cooled, the volume of the mercury will again diminish, and the fluid will sink in the tube, and we say that the temperature has fallen.

FIG. 462.

At equal degrees of temperature the top of the mercury will always occupy the same place in the tube; thus, on comparing a larger or a smaller thermometer with the first, both will rise and fall together, but the actual amount of

* See Professor Thomson's "Heat and Electricity," 2nd Edition, 8vo. 1840.

the rising and falling may be very different. If, for instance, the two bulbs are equal, but the tube of the one 10 times larger in its bore than that of the other, the mercury will, at an equal degree of temperature, rise 10 times higher in the narrower tube.

A thermometer of this kind can only serve to show whether a certain degree of temperature be present, or whether it be higher or lower, according as the top of the mercury stands higher or lower in the tube. Such an instrument might be of some use to science; but it is only by their graduation that thermometers can be rendered practically useful: thus enabling us to express the temperatures, to compare them, and thus ascertain the laws of heat.

It will of course be understood that only such glass tubes must be applied to thermometers as are perfectly cylindrical; and whether they are so, is known by observing if a globule of mercury suffered to pass up and down one of these tubes occupy an equal length in all parts of the tube.

After a tube has been blown out into a bulb, it must be filled with mercury; for this purpose the bulb is warmed, in order that the air contained within it may be expanded, and then the open end of the tube is rapidly plunged into the mercury (Fig. 463).

FIG. 463.

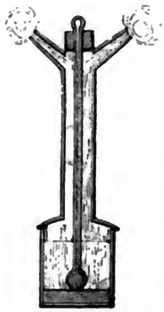
On the bulb cooling, the mercury ascends into the tube. It is sufficient here, if only a few drops reach the bulb. If we now again invert the instrument, and heat the ball a second time till the fluid begins to boil, the vapour of the mercury will soon fill the whole space, driving the air entirely out; and when the open end of the tube is again quickly plunged into the mercury, we may be sure of the bulb becoming entirely filled.

Before the thermometer is closed it must be *regulated;* that is to say, as much mercury must be added or taken away as is necessary to make the amount correspond to the medium temperature for which the thermometer is intended: it must then be hermetically closed.

The graduation of thermometers consists in marking *two fixed points* on the tube, and then dividing the intervening space into equal parts. For these points, the boiling and freezing points of water are generally taken. To determine the latter, the thermometer ball and the tube, as far as it is filled by the mercury, are plunged into a vessel filled with finely pounded ice, Fig. 464. If the temperature of the surrounding air be higher than the

FIG. 464.

FIG. 465.



freezing point, the ice will melt, and the whole mass will assume the fixed temperature of the freezing point. The thermometer will also soon acquire this temperature, and from that moment it will remain perfectly stationary, when we have only to mark with accuracy the point of the tube where the top of the column of mercury stands. This point is first designated by a line of ink, and subsequently marked by a diamond.

In order to determine the boiling point, we take a vessel with a long neck, (Fig. 465), and heat distilled water within it to the boiling point; after the boiling has gone on some time, all parts of the vessel will be equally heated, and the vapour will escape at the lateral openings; the thermometer is then surrounded on all sides by vapour, the temperature of which will be the same as that of the upper layer of water. The mercury will soon rise to a point at which it will remain standing, and which it will not exceed. This point is designated as 0. If at this moment the height of the barometer be not exactly 760^{mm}, a correction must be made, the amount of which will be given when we treat more fully of boiling. In the centigrade thermometers the interval between the two fixed points is divided into 100 parts, and the thermometer scale thus made.

All thermometers constructed in this manner are comparable instruments; that is to say, they exhibit an equal number of degrees at equal temperatures.

Mercurial thermometers may be constructed, which go to the 360th degree; but beyond this it is not expedient to raise them, for fear of approaching too nearly to the boiling point of mercury, which is 400^0 C. Below zero, the graduations of mercurial thermometers may go correctly as far as — 30^0 C. or — 35^0 C.; but beyond this we should approach too nearly to — 40^0 C., the freezing point of mercury. As we approximate to the temperatures in which bodies change their aggregate condition, their expansion is no longer regular.

All thermometers are not graduated according to the centigrade scale. In Germany and France *Reaumur's* thermometers are much used, which are divided into 80^0, although for scientific investigations the centigrade division of *Celsius* is almost exclusively applied to thermometers.

It is, however, easy to reduce *Celsius'* scale to that of *Reaumur*, and *vice versâ*; for as

$$100^0 \text{ C.} = 80^0 \text{ R.},\ 1^0 \text{ C.} = 0{,}8^0 \text{ R., and } 1^0 \text{ R.} = 1{,}25^0 \text{ C.}$$

Consequently x^0 C. = x, 0,8° R., and n^0 R. = n . 2,25° C. We may thus express the same thing in words: In order to change *Reaumur's* scale to that of *Celsius*, we multiply the number of the *Reaumur* scale by 1,25, or by $\frac{5}{4}$ths. If, on the other hand, we want to change *Celsius'* degrees into the *Reaumur* scale, we multiply the given number of the degrees by 0,8, or what is the same, by $\frac{4}{5}$ths.

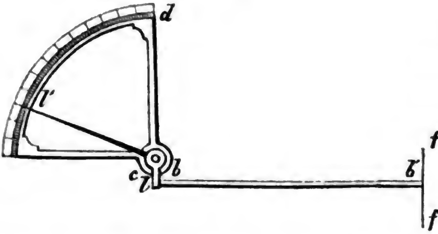
In England *Fahrenheit's* scale is exclusively made use of, the 0 of which does not correspond with those of the two above-mentioned scales. The null point, or 0 of *Fahrenheit's* thermometer agrees with the graduated line — $17\frac{7}{9}$ths of *Celsius*. Its melting point for ice is 32°, and the boiling point of water at 212°; so that the interval between the two is divided into 180 degrees. According, therefore, to their absolute value, 180° F. = 100° C.; consequently 1° F. = $\frac{5}{9}$°ths C., and 1° C. = $\frac{9}{5}$°ths F.

It is necessary, however, before we attempt to reduce the degrees of one of these thermometers to the scales of the others, to take into account that their zero points do not coincide. On changing *Fahrenheit's* scale into that of the *Celsian* thermometer, we must subtract 32 from the given fundamental number, and multiply the remainder by $\frac{5}{9}$: thus we have $x^0 \text{ F.} = (x - 32)\, \frac{5}{9}{}^0 \text{ C.}$ On changing the *Celsius* or centigrade scale into that of *Fahrenheit*, we multiply it by $\frac{9}{5}$ and add 32 to the product; consequently $y^0 \text{ C.} = (y \cdot \frac{9}{5} + 32)^0 \text{ F.}$ In order to facilitate a comparison of the different scales, we give the following table.

Celsius.	Reaumur.	Fahrenheit.
— 20	— 16	— 4
— 10	— 8	+ 14
0	0	32
+ 10	+ 8	50
20	16	68
30	24	86
40	32	104
50	40	122
60	48	140
70	56	158
80	64	176
90	72	194
100	80	212

Expansion of solid bodies.—As the expansion of solid bodies by heat is inconsiderable, means must be devised for making it more apparent to the eye. This is most simply effected in the following way. A rod *b b′* (Fig. 466) made of the body to be examined is supported at one extremity against a firm obstacle *f f′*, whilst its other extremity rests against the shorter arm of an angular lever, *l c l′*, that can rotate round the fixed point *c*. If now the end *l* of the shorter arm be pushed onward by the expansion of the rod *b b′*, the other end *l′* will traverse a much wider space; and we may in this manner make even the slightest prolongation of the rod *b b′* perceptible, provided the length *c l′* be very large in proportion to *c l*.

FIG. 466.



By aid of apparatus, the construction of which essentially rests upon the above-mentioned principles, the expansion of many bodies has been ascertained. The following list will give a few of the most important of these.

For an elevation of temperature from 0 to 100° C., we have these expansions:

Platinum . . .	about	0,00086	or	$\frac{1}{1167}$
Glass on the average .	„	0,00087	„	$\frac{1}{1147}$
Steel (hard) . .	„	0,00124	„	$\frac{1}{807}$
Iron	„	0,00122	„	$\frac{1}{819}$
Copper . . .	„	0,00171	„	$\frac{1}{584}$
Tin	„	0,00217	„	$\frac{1}{462}$
Lead	„	0,00285	„	$\frac{1}{351}$
Zinc	„	0,00294	„	$\frac{1}{340}$

A steel rod, therefore, which at 0° has a length of 807 lines, will have a length of 808 lines at 100°; a zinc rod of only 340 lines in length will expand 1 line at an increase of temperature from 0 to 100°. Amongst all the above given bodies, platinum expands the least, and zinc the most.

Almost all solid bodies expand equally between 0 and 100°; that is, their expansion is proportional to the elevation of temperature. At an increase of temperature from 0 to 10° copper

expands 0,000171, at an elevation of temperature from 0^0 to 1^0 it expands 0,0000171 of its length at 0^0.

The number expressing the extent of length from 0^0, which a body expands at an elevation of temperature from 0 to 100^0, is termed the co-efficient of the expansion of length. The above table gives the co-efficients for platinum, glass, steel, &c.

Cubic expansion is the increase in the volume of a body produced by an elevation of temperature. Here, too, the volume of the body at 0^0 is taken as the starting point, and by the co-efficience of expansion we here understand the number giving the quantity which expresses by how much of its original volume at 0^0 a body on heating it to 100^0 C. expands. If we say that the co-efficient of the expansion of mercury is 0,018, it means that mercury expands at an elevation of temperature of 100^0 about $\frac{18}{1000}$ of its volume at 0^0. If we know the co-efficients of expansion and the volume of a body at 0^0, we may reckon its volume at any degree of temperature, provided that the expansion of the body be regular up to this degree of temperature.

In liquid and gaseous bodies the expansion can be determined directly by experiments, whilst in solid bodies it must be estimated from the linear expansion observed.

The co-efficient of expansion of solid bodies is three times as great as the co-efficient for the linear expansion of the bodies.

We may convince ourselves of this by the following reasoning. Let l be the side of a cube at 0^0, then l^3 is its volume, which we will designate by v; if the cube be heated to the 100^0 C. each side becomes l, $(1 + r)$, consequently the contents of the cube are:

$$v' = l^3 (1 + r)^3 = l^3 (1 + 3 r + 3 r^2 + r^3).$$

But as r is a very small quantity, we may disregard its higher powers, when the value of v' will consequently be reduced to

$$v' = l^3 (1 + 3 r) = v (1 + 3 r).$$

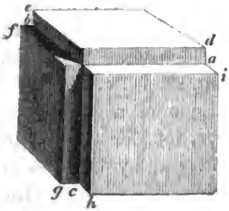
The volume v is consequently increased about $3 r v$; and the co-efficient of expansion for the volume is consequently $3 r$.

We will endeavour to make this more apparent by a geometrical figure.

Let $a\ b\ c$ be a cube formed of a solid body at 0^0 (Fig. 467). If this cube were only expanded upward at an elevation of temperature of 100^0, its volume would increase as much as the quadratic plate $a\ d\ e\ b$, whose solid contents are $v\ r$, if v be the volume of the original die, and r the linear co-efficient of expansion. If the cube only

expanded towards the left side, it would be increased by an equally large plate $c\,g\,b\,f$, and, finally, a third plate $b\,i\,h\,c$, whose contents are likewise $r\,v$, would be the result of the expansion of the body anteriorly. The cubic contents of these three plates together are $3\,r\,v$. To complete the estimation of the increase by heat of the cube, we ought to add the contents of the corners, which are filled up at the places where every two of the above-mentioned plates meet together at the edges; but the amount of this is so inconsiderable, that it may be disregarded, since the size of the linear expansion $d\,a$ is very small in comparison with the lengths of the sides of the original cube, and we may thus, without serious error, assume $3\,r\,v$ to be the whole increase of the volume.

FIG. 467.



The *co-efficient* for the expansion of length in glass, for instance, is 0,00087, at an elevation of temperature from 0 to 100⁰, consequently a mass of glàss will expand about 0,00251 of its volume; the same is the case with the contents of a glass vessel. If a glass vessel, at a temperature of 0^0, contain exactly 1000 cubic centimetres, its contents will at 100^0 have increased to 1002,51 cubic centimetres.

Expansion of fluids.—The apparatus in Fig. 468 may be used to determine the expansion of various fluid bodies. The neck of a glass vessel of corresponding size is so much contracted at one spot, that the part above may be in some degree considered as a funnel. The narrowest part of the neck *a* is marked in some way. The globe is now filled with the fluid to be examined, so that it reaches above *a*, within the funnel, and the whole is cooled down to 0^0, while the apparatus is entirely surrounded with melting snow, or ice. When the fluid is cooled to 0^0, all the fluid standing above the mark must be removed. If we weigh the filled globe, abstracting from the weight found, that of the glass vessel, we shall obtain the weight of the fluid rising in the globe at 0^0. As soon as the globe is warmed, the fluid will expand, ascending above the mark *a* on the funnel. When we have warmed it to a certain degree of

FIG. 468.

temperature, as 100^0, we must remove all the fluid standing above *a*, and weigh it a second time. After this, it will be easy to calculate the apparent expansion.

The expansion thus determined is, as we have already remarked, only the apparent one; the true expansion of fluids being only found on adding the increase, by heat, of the contents of the glass vessel to the apparent expansion.

At an elevation of temperature from 0 to 100^0, the expansion of the volume at 0^0, is as follows:

Mercury .	about	0,018	
Water . .	„	0,045	
Spirits of wine	„	0,100	
Oil . . .	„	0,100	nearly.

As we see, the expansion by heat is *very* considerable in the case of spirits of wine and oil, a circumstance that ought to be attended to in commerce.

Most fluids do not expand regularly between 0 and 100^0. This is best seen by constructing thermometers of different fluids, and comparing them with one of mercury. If, for instance, we heat a water thermometer which has long been exposed to a temperature of 0^0, it will not immediately rise, but will first sink, and only begin to rise when the temperature has been raised to $5\frac{3}{4}^0$. If we take into account the expansion of the glass, it will be found that water has a maximum density at 4^0, that is, at 4^0 water is denser than at any other temperature. Water of 4^0 will expand whether we heat or cool it.

Spirits of wine do not expand regularly, on which account a spirit thermometer does not, at all temperatures, correspond with one of mercury.

Expansion of gases.—Gases expand by heat far more than solid and fluid bodies, and their co-efficients of expansion are the same for all temperatures; further, gases always expand in proportion to the elevation of temperature.

At an elevation from 0 to 100^0, the expansion of gases amounts to 0,365 of their volume at 0^0.

Different methods have been used to ascertain the co-efficients of expansion for gases, amongst which, however, the following is the most simple. A glass bulb is blown at the one end of a thin glass tube, as seen in Fig. 469, while the other end is drawn to a fine point. On immersing the bulb in boiling water, in such a manner,

of course, that the point shall project tolerably far beyond the fluid, the air within it will soon be heated to 100°, and, in consequence of this, will partially escape from the ball. The point must now be closed over a spirit lamp, and the bulb suffered to cool gradually; when it has become quite cold we must then invert it, put the point into the mercury, and break it off; the mercury will now naturally force its way into the ball, because the air within has been rarefied by the previous heating.

FIG. 469.

If we cool the ball to 0°, by means of melted snow laid upon it, the mercury forcing its way in, will exactly fill the space in which the air remaining in the bulb has expanded at an elevation of temperature from 0 to 100°. If we determine by weight the quantity of mercury that has entered, we shall obtain the weight of the amount of mercury which the whole bulb is capable of containing; and thus, consequently, we may calculate the co-efficients of expansion of air.

CHAPTER II.

CHANGE OF THE STATE OF AGGREGATION.

Fusion.—We may easily see that *fusion*, that is, the transition of a body from the solid to the fluid condition must be a phenomenon of heat, and that no other power in nature but this is capable of producing a similar effect. We may break ice and reduce it to powder, and we may expend every mechanical power upon it; but yet it will not be converted into water until acted upon by heat. The same is the case with lead, wax, &c. Whether a body be solid or fluid depends, therefore, entirely and solely on its temperature. At any other distance from the sun than the one occupied by it, the earth would present a very different aspect; at a greater approximation to that luminary most metals would be in a constant state of fusion, while at a greater distance from it the sea would be a solid mass; there would be no running water, and probably no fluid, on the circula-

tion of which the phenomena of animal and vegetable life depend.

As heat penetrates and expands all bodies, the question naturally arises, whether all solid bodies are fusible? In this respect great differences present themselves amongst bodies; some are *easily fusible,* and pass into a fluid condition at even a low temperature, as, for instance, ice, phosphorus, sulphur, wax, fat, &c.; others again require high temperatures to reduce them to fusion, as tin, lead, &c.; finally, there are bodies which only melt at very high temperatures, as gold, iron, platinum. No success has as yet attended the attempts made to fuse charcoal, although many natural philosophers maintain that they have observed traces of fusion at the edges of the diamonds submitted to experiment. Judging from analogy, we must conclude that there are no absolutely infusible bodies, and that all would melt if exposed to a sufficiently high degree of temperature.

Organic bodies undergo, for the most part, a chemical decomposition by the action of heat before they are reduced to a state of fusion.

On a body passing from the solid to the fluid condition, we observe two remarkable phenomena. *In the first place,* it remains solid up to a certain fixed temperature, which is always the same for the same body, and at which alone fusion begins; and *secondly,* the temperature does not change during fusion, let the amount of heat imparted be what it may. Heat is, therefore, absorbed during fusion, and incorporates with the body without producing any further action on the feelings or on the thermometer. The *invariability of the fusion point* and the *absorption of latent heat* are two essential conditions of fusion.

The following table gives the point of fusion for different substances.

Wrought English iron	1600	degrees.
Soft French iron	1500	„
The least fusible steel	1400	„
The most easily fusible steel	1300	„
Gray cast-iron, second smelting	1200	„
Easily fusible gray cast-iron	1050	„
Gold	1250	„
Silver	1000	„
Bronze	900	„
Antimony	432	„

Zinc	360	degrees
Lead	334	„
Bismuth	256	„
Tin	230	„
Amalgam, formed of 5 parts tin, 1 part lead	194	„
Sulphur	109	„
Amalgam of 8 parts bismuth, 5 parts lead, 3 parts tin	100	„
„ „ 4 parts bismuth, 1 part lead, 1 part tin	94	„
Sodium	90	„
Potassium	58	„
Phosphorus	43	„
Stearic acid	70	„
Soft wax	68	„
Yellow wax	61	„
Stearine	49 to 43^0	
Spermacetti	49	„
Acetic acid	45	„
Soap	33	„
Ice	0	„
Oil of turpentine	—10	„
Mercury	—39	„

Latent heat.—A considerable degree of heat is necessary to convert ice or snow at 0^0 into water at 0^0. The heat is *latent* in the water, and is alike imperceptible to the feelings or to the thermometer.

If 1lb. of water of 79^0 be mixed with 1lb. of snow of 0^0, we shall obtain 2lbs. of water of 0^0. All the heat, therefore, which was contained in the hot water, is no longer to be detected by the thermometer, having alone been applied to the purpose of converting snow at 0^0 into water at 0^0.

If snow, or pounded ice at about -10^0 be mixed with common salt at about -10^0, the two will combine to form a liquid solution of salt; and the thermometer will in the mean time fall more and more, owing to the large quantity of heat that is latent in the liquefaction of two previously solid bodies. On this principle depend the so called *freezing mixtures.*

If we designate as 1 the amount of heat necessary to raise the temperature of 1lb. of water to 1^0, the amount of heat which

becomes *combined* or *latent* by the fusion of 1lb. of snow will be equal to 79.

Heat is *latent* as well in the melting of ice and snow, as also in the fusion of other bodies. The following are the values of the latent heat of several bodies according to *Irvine's* calculations:

Sulphur . . .	80
Lead . . .	90
Wax . . .	97
Zinc . . .	274
Tin	278
Bismuth . . .	305

The signification of these numbers is easily understood; for instance, as 1lb. of snow requires for its fusion 79 units of heat, that is, 79 times as much heat as is necessary to raise the temperature of 1lb. of water 1^0, 80^0 units of heat are requisite to fuse 1lb. of sulphur, and 90, 97, and 274, respectively, for the fusion of 1lb. of lead, wax, or zinc, &c.

As heat is latent in the fusion of a solid body, so likewise an absorption of heat is effected on a solid body being dissolved into a fluid condition; we may easily convince ourselves of the truth of this on throwing a pulverised, easily soluble salt, as saltpetre, in water, and promoting the solution by stirring; the temperature of the water will fall several degrees during the process.

Pulverised glauber salts, over which muriatic acid has been poured, give a fall of temperature of + 10 to — 17^0 C.

Solidification.—On the transition of a body from a fluid to a solid condition, we observe phenomena precisely analogous to those exhibited in the process of fusion; in the first place, it only occurs at a definite temperature corresponding with the fusion point, and secondly, all the latent heat that had been absorbed by fusion is again liberated on solidification taking place.

The phenomenon of the liberation of latent heat on the solidification of fluid bodies was proved in the following manner: In the year 1714 Fahrenheit made the observation, that under certain circumstances pure water may be cooled to from 10^0 to 12^0 without freezing. This may often be noticed in the open air, but the phenomenon can be best exhibited by being careful to expose the cooling water to but an inconsiderable pressure of air or vapour. This may be effected by making water boil in a glass tube that has been drawn out into a fine point, and sealing it when we suppose that all the air has been driven out by

the steam. There will then only be steam in the glass above the water, which will exercise but an inconsiderable degree of pressure at a low temperature. On exposing such a glass tube as this to a temperature of — 12°, the water will remain fluid; but when the vessel is shaken, the mass of water will suddenly freeze. If a thermometer has been inserted into the interior of the glass tube, on which we may be able to discern the low degree of temperature, standing at — 12°, we shall see how the mercury will instantaneously rise to 0° as the water becomes solid.

The rapidity with which the solidification occurs under these circumstances, and the rising of the thermometer, are phenomena which easily admit of explanation. The latent heat of the first particles that freeze, passes over to the next particles, which are still fluid. They are certainly warmed, but not sufficiently so to hinder their solidification, hence the two-fold action of solidification and heating.

When solidification takes place at the ordinary freezing point, it always occurs but slowly, and without any elevation of temperature. If, for instance, water freeze at 0°, the solidification will generally begin simultaneously at various points, and here the particles first solidified will give off their latent heat to the neighbouring parts, which will thus be maintained in a fluid condition for a few minutes longer. This is the cause of our observing thin ice plates, and fine needles of ice diffusing themselves in various ways over the fluid mass. In this manner the latent heat is distributed by degrees, and were it not for the presence of this heat, the whole fluid mass would, on being cooled to the freezing temperature, at once become solid.

Heat is also liberated every time a fluid enters into a solid combination with another body. Thus, burnt gypsum and burnt lime combine with water to form solid bodies, named hydrates by the chemists. Water passes, therefore, by this combination into a solid form, and, consequently, heat must be liberated. We thus explain the intensity of heat occasioned by throwing water on burnt lime.

Formation of vapour.—When a fluid is in contact with the air, its quantity diminishes by degrees, until it wholly disappears after a longer or shorter period of time. The water which covers the soil after rain cannot resist the action of a dry wind or the sunshine, but will disappear, not only because it has been imbibed by the earth, but also because it has evaporated in the air.

The phenomenon of evaporation goes on more rapidly on letting water boil in a flat dish over the fire; in a short time all the water will have disappeared, although it has not been absorbed by the dish. Hence, it follows, that fluids change their aggregate condition, becoming invisible and expansible like gases. We designate by the term *vapour* any fluid that has passed into a gaseous condition.

The erroneous opinion long prevailed that vapours could not exist by themselves as such; that they were dissolved in the air in the same manner as salt is in water; and, finally, that in order to make fluids assume the form of gas, it was necessary to have some solvent medium as the air, like the soluble power of water to make salt fluid. In order to prove the incorrectness of this view, and at the same time to be able to study the true laws of the formation of vapour, we must take care to conduct the process in a vacuum. For this purpose the Torricellian vacuum is admirably well adapted, not only from its furnishing us with a perfect vacuum; but also, because the depression of the moveable column of mercury affords us a means of measuring the expansive force of vapours.

FIG. 470.

Let us assume that we have placed three Toricellian tubes side by side in a broad vessel $v\ v'$, Fig. 470, filled with mercury, the fluid level will be equal in all three; if, however, by means of a curved pipe we pour a little water into a tube b', it will rise to the Torricellian vacuum, and the mercury will then instantly fall several millimetres. This depression cannot be ascribed to the weight of the small layer of water floating on the mercury; and in like manner, provided we have taken water which has been perfectly freed from air by boiling, as is necessary to the success of the experiment, we are unable to ascribe this depression to the air liberated from the water. Vapours must therefore have been developed in the water, which, like gases, possess a tension; for these vapours act precisely in the same manner as if a small portion of air had been suffered to rise in the vacuum.

The amount of depression affords at once a standard by which to measure the power of tension in the vapour or the steam of the water. If we assume that the surface of the mercury t depressed by

the vapour stands 15^{mm} lower than that c of the other barometer, above which there is still a perfect vacuum, it will be clear that the vapour will press upon the surface t with a force equal to a column of mercury 15^{mm} in height. This depression of 15^{mm} is, therefore, actually the measure of the force of tension of the steam.

If we had put sulphuric ether, for instance, or any other fluid instead of water into the third barometer tube b'', we should have observed a far more considerable amount of depression than in the water, for at a medium temperature the depression amounts to almost half the height of the barometer b, from which it follows, that under these circumstances the vapour of ether has a force of tension equal to the pressure of almost half an atmosphere.

Maximum of the force of tension of vapours.—The tendency of vapours to expand is carried, as in gases, *ad infinitum;* that is to say, the smallest quantity of vapour will diffuse itself through every part of a vacant space, be its size what it may, exercising a more or less considerable pressure upon the walls. The smallest quantity of water is therefore capable, in the form of vapour or steam, of filling a space of many thousand cubic metres, in the same manner as does the air. Although vapours have an illimitable force of expansion, their force of tension cannot, as in the case of gases, be increased at will by an increase of pressure. For to whatever extent we compress a given quantity of air, its elasticity will, according to *Mariotte's* law, increase in the same proportion as its volume diminishes. On attempting to compress vapours, in order by that means to augment their elasticity, we soon reach a point where the vapour *condenses,* and returns to its fluid condition. The *limit of resistance,* at which further compression produces no increase of elasticity of the vapour, but renders it fluid, is termed the *maximum of the tension of vapour.*

FIG. 471.

In order to show by experiment this characteristic difference between gases and vapours, the most efficient apparatus is the one described at page 101, excepting only that ether is put in the place of the air in the tube of the barometer. For this purpose the Torricellian tube is carefully filled with mercury, the air being as much as possible removed by boiling or other means. If the tube be thus filled to the height of from 1 to 2 centimetres with mercury, the remainder of the

tube must be filled up with ether, on which the tube is inverted and immersed in the vessel *c n*. The ether immediately rises, one portion remaining fluid while the other is evaporated in the vacuum, which occasions a depression of the column of mercury. If, for instance, the column *n s* has only a height of 400^{mm}, while it would be 760^{mm} in height if there were a vacuum above, then the force of tension of the vapour of ether is equal to 360^{mm}. If now we press the Torricellian tube *c c'* more deeply into the tube *c c*, filled with mercury in order thus to diminish the space filled with vapour of ether, we shall perceive that the mercury column *n s* remains quite unchanged. If there is air instead of ether vapour in the upper part of the tube, we know that when the volume of included air is diminished by being pressed down, its elasticity also increases, so that the height of the mercury column in the barometer decreases, (page 101.) Here the case is quite different with regard to vapour, for the volume of the vapour of ether will be diminished without the elasticity being increased, the height of the column *n s* remaining the same.

The more, however, that we press the tube, the more does the quantity of the ether increase, the diminution of the space occupied by the ether vapour acting in such a manner that a portion of the vapour is again condensed to fluid ether, whilst the remaining vapour does not change its force of tension. If, therefore, we compress the space filled with the ether vapour to $\frac{1}{2}$, $\frac{1}{3}$, or $\frac{1}{4}$, &c., $\frac{1}{2}$, $\frac{1}{3}$, or $\frac{1}{4}$ &c., of the vapour will likewise be condensed. If we continue to press down the tube, we shall soon reach a point at which all the vapour will be condensed, so that there will be only fluid ether over the column of mercury; it is, however, extremely difficult fully to remove every globule of vapour, as the ether always contains absorbed air.

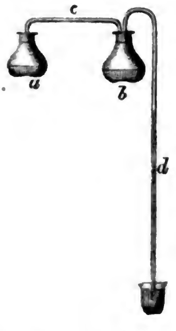
On again raising the tube, the column of mercury will always retain the same height, *n s*, whilst the fluid layer of ether will continually diminish: showing that vapour re-forms immediately again to fill the enlarged space, and reaches the maximum of the power of tension. If, however, we only put a little ether into the tube, and raise it sufficiently to let all the fluid escape, the mercury will also ascend on continuing to raise the vessel; the ether vapour is consequently no longer at the maximum of the force of tension, and will exhibit exactly the same relations as a gas on a further increase of its volume.

Equilibrium of the force of tension in an unequally heated space.—We may easily convince ourselves of the important influence exercised by the degree of temperature on the maximum tension of vapours, by observing the inequality in the depression of the barometer tube during the above-named experiment, when conducted at different temperatures. For instance, with ether at 0^0 we obtain only a depression of 180^{mm}, whilst it amounts to 630^{mm} at 30 degrees. Phenomena which are ever present before us furnish us with many proofs of the truth of this. The vapour of water, as it is formed upon the surface of rivers and lakes, has only an inconsiderable degree of tension; but when water is made to boil, the force of tension of the steam is so great as to be able to equipoise the pressure of the atmosphere, whilst at a still higher temperature this tension augments to such a degree as to occasion the most fearful explosions in the boilers.

We may conjecture from this what the maximum of the tension of steam may be in a space which is unequally heated in different parts. According to the conditions of the equilibrium of gaseous bodies, the steam must have an equal degree of tension at all parts of this space; and as the force of tension of the steam cannot be so great at the cooler as at the warmer parts, it is evident that the tension of the vapour must be the same throughout the whole space as at the coldest places; that, consequently, the vapour cannot at the warmer parts reach the maximum of the force of tension corresponding to the higher temperature.

This principle may be rendered apparent by the help of the apparatus (Fig. 472.) Two glass bulbs, *a* and *b*, each containing a little ether, are connected by a tube *c*, a second curved tube *d* passing through the cork that closes *b*. If now the ether in *a* and *b* be brought to the boiling point, (which is best effected by plunging the tube into hot water) the vapour will escape through the tube *d*, carrying away the air from the apparatus. We now plunge the lower end of the tube *d* in a vessel filled with mercury, removing the sources of heat by which the ether has been made to boil; *a* and *b* will then immediately be cooled down to the temperature of the surrounding air, the force of tension of the vapour in the apparatus will diminish to a definite degree, and the mercury consequently rise to a definite height, dependant upon the temperature of the surrounding air. If we

FIG. 472.



plunge one bulb into snow or some freezing mixture, the mercury will forthwith rise as high as if both bulbs had experienced the same degree of cooling.

Estimate of the force of tension of the vapour of water.—Different kinds of apparatus have been applied to the purpose of determining the force of tension of steam, according as we wish to calculate it for a temperature between 0^0 and 100^0, below 0^0 or above 100^0.

The apparatus represented in Fig. 473 is used for temperatures varying between 0^0 and 100^0. It consists of two barometer tubes immersed side by side in the same vessel; the first of these tubes forms a complete barometer, and in the second there is, above the mercury, a little water, which forms a little vapour in the vacuum. The two tubes are plunged, by means of an iron rod, into a sufficiently deep glass vessel; this vessel is quite filled with water, which may be warmed to any temperature we please between 0^0 and 100^0. The temperature of this water, which may be determined by properly applied thermometers, is at the same time that of the two barometers and of the steam in the one. In order to obtain the degree of elasticity of the steam corresponding to each degree of temperature, we have only to determine in what relations the depression of the steam barometer stands to the height of the column of mercury in the perfect barometer.

FIG. 473.

FIG. 474.

The following method may be adopted for measuring the force of tension of steam above 100^0. A wider vessel is fixed into a tolerably long glass tube, Fig. 474, somewhat in the same manner as the cistern of a barometer; the longer and shorter tubes are both open at the top. On pouring in mercury, it will of course rise equally high in both tubes. The fluid to be tested is then poured upon the mercury in the wider tube, and after being kept up to the boiling point for some time after all the air has been expelled, the tube is sealed. If we put the vessel into a fluid, the temperature of which is above the boiling point of the enclosed fluid, vapour will be formed, which presses upon the mercury (in the vessel) causing it to rise in the long tube. The difference of the mercury level in the vessel and the tube indicates how much the power of tension of the vapour exceeds the amount of the pressure of the atmosphere.

The apparatus is fastened to a graduated stem, both for the purpose of being able to measure the height to which the column of mercury is raised, and also to protect the tube from being struck or broken. If the tube be long enough, we may, by means of this apparatus, measure the tension of steam at 3 or 4 atmospheres.

In order to be able to measure higher tensions, we need only fuse together the ascending tube, so that a definite quantity of air may be inclosed in it. When the steam in the vessel drives the mercury into the tube, the inclosed air becomes compressed, and we may easily compute the force of tension of the steam by the difference in the height of the two surfaces of mercury.

The following tables contain the maximum of the force of tension of steam for different temperatures:

Degrees.	Force of tension of steam in millimetres.	Pressure upon 1 square centimetre in kilogrammes.
0	5	0,007
10	9	0,013
20	17	0,023
30	30	0,042
40	53	0,072
50	89	0,126
60	145	0,196
70	229	0,311
80	352	0,478
90	525	0,714
100	760	1,033

Force of tension in atmospheres.	Corresponding Temperatures.	Pressure upon 1 square centimetre expressed in kilogrammes.
1	100	1,03
2	121	2,07
4	145	4,83
6	160	6,20
8	172	8,26
10	182	10,33
15	200	15,49
20	215	20,66
25	226	25,82
30	236	30,99

We see from these tables, that at the temperature of the boiling point, the force of tension of steam equipoises the pressure of the atmosphere. This is universally true: the force of tension of the vapour formed from any boiling liquid is always equal to the pressure on the surface of the liquid; for if it were less, the vapour could not remain in the interior of the liquid in the form of bubbles, and if it were more considerable the vapour must have been previously formed. The vapours of all liquids have an equal force of tension at the boiling point. *Dalton* was of opinion that the force of tension must be equal at an equal number of degrees above or below the boiling point; it would only be necessary, therefore, according to this law, to have a table for the force of tension of saturated steam, and to know the boiling point of a liquid, in order to ascertain the force of tension of the vapour at any temperature. The boiling point of alcohol, for instance, is 78^0, the force of tension of the vapour of alcohol at 113^0, that is, 35^0 above the boiling point, must be equal to the force of tension of steam at 135^0, which is 2280^{mm}, or 3 atmospheres. According to this law, the force of tension of the saturated vapour of alcohol at 0^0 would be equal to 19^{mm}, because this is the force of tension of steam at a temperature 78^0 below the boiling point of water. From the experiments of many natural philosophers it is evident, however, that this law is not correct.

The force of tension of vapour increases, as we see, in a far more rapid ratio than the temperature; that is to say, a definite elevation of temperature produces a far greater increase of the force of tension at high than at low degrees of temperature. Thus, while an elevation of temperature from 100^0 to 121^0 (that is, about 21^0) increases the force of tension of steam about 1 atmosphere; it will increase at an elevation from 126^0 to 236^0 (that is, at only 10^0 more) about 5 atmospheres, consequently between 226^0 and 236^0, an elevation of temperature of only 2^0 would suffice to raise the force of tension of steam to about 1 atmosphere.

There are two reasons for the increase of the force of tension at an increasing temperature. Let us suppose some enclosed space to be filled by steam at 100^0, that is, with a vapour whose force of tension equals 1 atmosphere, and that there is no more water in this space, it being entirely precluded from ingress. If now the temperature of this space be raised 121^0, the vapour will strive to expand, and since it will not be able to do so, its force of tension will increase, although not much; the vapour will then be no longer saturated, but quite in the condition of a gas. If, however, there still

remain any water in this space, then, in consequence of the increase of temperature, a new quantity of vapour will be formed of 1 atmosphere; if, then, the force of tension increases by 1 atmosphere, the vapour will become denser, when, in consequence of its greater density, it will exercise a greater pressure.

1 cubic inch of water yields:

1700	cubic inches of saturated steam at			100^0
897	„	„	„	121
207	„	„	„	182

There are liquids whose boiling points lie below the average temperature of the air, and such bodies can of course not become liquid under ordinary circumstances, being at the usual temperature, and the usual pressure of the atmosphere, in a gaseous form, such gases must, therefore, be compressed and cooled, in order to become liquid. Thus, for instance, we find sulphurous acid at -10^0, and when rendered liquid under pressure in a glass tube, its vapours exert a pressure of about 5 atmospheres, even at 25^0.

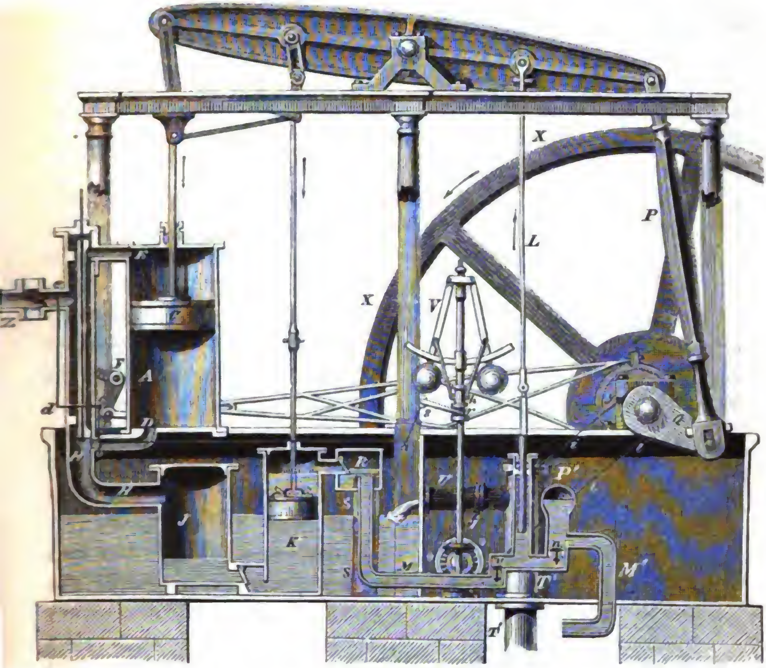
Cyanogen gas, ammonia, carbonic acid, &c., also admit of being condensed into liquids by compression and cooling. The vapour of liquid carbonic acid has at 0^0 a force of tension of 36, and at 30^0 a force of tension equal to 73 atmospheres.

The Steam Engine.—Steam has, in more recent times, as we all know, been used as a moving force, and it is owing to the introduction of the steam engine that industry and general intercourse among men have made such rapid advances. Passing by the older forms of this machine, we will at once enter upon the consideration of Watts' steam engine. The cylinder *A* is made air-tight below as well as above, so that the atmospheric air cannot pass on either side upon the piston *C*. The steam which is conducted from the boiler through the tube *Z* of the engine, enters the cylinder alternately at *E* and *D*. We shall presently enter fully into the manner in which this alternation is produced. In the position of the engine, as seen in our figure, the steam enters above at *E*. The steam in the lower part of the cylinder escapes at *D*, in order to reach the condenser *T* through the pipe *H*, and is there condensed; the steam presses above upon the piston *C*, while below it there is a rarefied space, the piston therefore is in the act of descending.

The condensation of the steam in the cylinder on the one side of the piston takes places by the latter being brought into connection with the above-mentioned condenser; this is the space marked

J, being connected either with the lower or the upper part of the cylinder. Cold water is constantly poured into the condenser,

FIG. 475.



and a condensation of the steam thus effected; but by this means, in accordance with the principles illustrated by Fig. 472 (page 450), the force of tension of the steam is diminished in that part of the cylinder which is connected with the condenser; the steam then passes from the cylinder into the condenser, to be there condensed.

Many contrivances have been proposed for making the steam enter the cylinder alternately from above and below, whilst the steam escapes from the other side of the piston towards the condenser. The simplest of these arrangements is the *cross-cock*. This is perforated, as seen in Fig. 476. The tube *K* leads to the boiler, *C* to the condenser, *O* to the upper, and *U* to the lower part of the cylinder. If the cross-cock be placed in the position

FIG. 476.

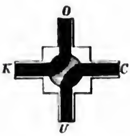
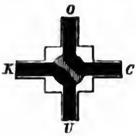


FIG. 477.



as seen in Fig. 476, the steam will flow from the boiler into the upper part of the cylinder, whilst its under part is connected by the tubes U and C, with the condenser. When the piston has penetrated far into the cylinder, the cross-cock is brought, by a half a revolution, into the position seen in Fig. 477. Now the tubes K and U are connected, the steam, therefore, enters, escaping from the upper part of the cylinder through the tubes O and C towards the condenser; now, therefore, there must be an upward directed motion of the piston.

The cross-cock has not proved to be applicable to larger engines, owing to the impossibility of making the channels of the cock wide enough to admit of the passage of the requisite quantity of steam. The *sliding valve* is now most generally made use of, it is applied to the engine we have delineated, and is represented in Figs. 478 and 479, in its two extreme positions, being drawn on a

FIG. 478.

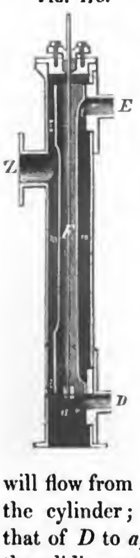


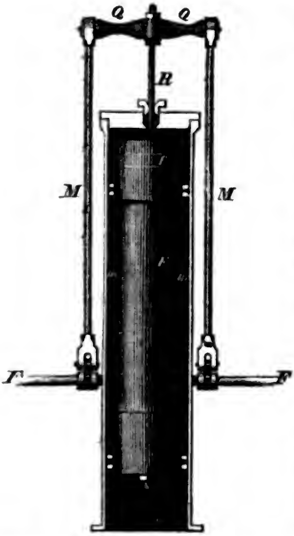
FIG. 479.

large scale. The steam passes through the tube Z to a receiver, from which the tubes D and E lead to the cylinder. This receiver is divided into two separate spaces by means of the slide F. The middle portion m of the receiver is quite shut off from the upper part a', and the lower part a, whilst these two spaces are themselves connected by the cavity of the slide. The steam now flows from the boiler into the space m, the spaces a and a remaining connected with the condenser. If the sliding valve have the position of Fig. 478, the steam will flow from m through the communication E from above, into the cylinder; while the steam passes under the piston, through that of D to a, and from thence to the condenser. If, however, the sliding valve lie in the position represented in Fig. 479, the

steam will flow from m through D from below into the cylinder, the steam above the piston will pass through E towards a', and from thence through the sliding valve to a, and finally reach the condenser.

The sliding valve has been represented in Fig. 480, as seen in the direction of Z, in order that we may form to ourselves a perfectly correct idea of its construction. The manner in which the slide is drawn up and down the machine, will presently be further considered.

FIG. 480.



The condenser T, Fig. 475, stands in a receiver partly filled with cold water, constantly flowing into the condenser from an opening not visible in our figure. The quantity of the water entering, may be increased or diminished at will, by means of a cock. The water is pumped out of the condenser by the pump K. As is well known, more or less air is always absorbed in all water, this is liberated in the boiler, and passes, together with the steam, through the engine into the condenser. In the same manner, air will be disengaged from the cold water flowing into the condenser. The steam will become condensed, while the air will remain in a gaseous condition. This air would, by degrees, accumulate in the condenser, and thus prevent the creation of a vacuum on the one side of the piston, if it were not at the same time carried off by the pump K, which has on that account received the name of an *air-pump*.

By means of this pump, the water is carried from the condenser into the receiver R, from which it is almost entirely discharged by the tube S. The heat which was latent by the evaporation of the water in the boiler, is again liberated by the condensation of the steam in the condenser; this liberated heat raises the temperature of the cold water thrown into the condenser; the water carried through the pump K towards R is therefore warm, on which account it is more advantageous than cold water for feeding the boiler. The water required for the boiler passes through the tube M to a

pump, which carries it through the tube *M′*. This pump, as well as the air pump, is put into motion by the engine itself; for instance, the pump rod *L* is attached to the beam, and is raised as the piston *C* descends, and is pressed down as the latter ascends. When the piston of the warm water pump, attached to the rod *L*, rises, the suction valve *v* opens, and at the descent of the piston, the valve *n*.

On the other side of the beam, exactly behind *L*, there is another pump rod, through which cold water is raised into the tube *T′*, and brought through *U* into the receiver containing the condenser.

Let us now consider how the upward and downward motion of the piston *C* is transmitted.

The piston rod moves, air and steam tight, through the stuffing-box in the middle of the upper cover of the cylinders; being connected with the end of the beam by a system of moveable rods, bearing the name of the *parallelogram*. The object of this contrivance is merely to establish a perfectly vertical motion of the piston rod, which could not be effected if the rod, or handle, were fastened directly to the end of the balancer; since it would, in that case, deviate alternately to the left and right, and consequently so much affect the stuffing-box, that the air-tightness would soon be destroyed.

The one end of the working beam is alternately drawn up and down by the piston, while its other extremity has constantly an opposite motion; that is to say, when the piston *C* rises, the right arm of the beam goes down, and *vice versâ*. The upward and downward motion of the beam is constantly changed into a circular motion by the connecting rod *P*, and the crooked handle *Q*. The axis of this handle is the main axis of the machine which is to be set in motion, and around this axis moves the fly-wheel *X*.

The motion of the piston *C* is very irregular. As it comes to a state of rest at the upper and lower end of the cylinder, and then reverses its motion, it is evident that it cannot perform its course with uniform velocity. Its velocity is greatest when it passes the middle of the cylinder, and diminishes the more it approaches either end. On considering the motion of the handle, we shall find, that with uniform velocity of revolution, the motion in a vertical direction is still very changeable. The handle stands in a horizontal position when the piston *C* is in the middle of the

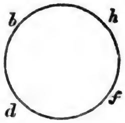
cylinder, at which moment the motion of the handle is in a vertical direction; this motion inclines, however, horizontally when the piston *C* attains its highest or lowest position. The vertical portion of the motion of the handle is perfectly similar to the motion of the piston, in proportion as the motion of the handle becomes more horizontal, the velocity of the piston diminishes, without any diminution in the velocity of the revolving action of the handle.

The diameter of the path traversed by the handle *Q*, is of course equal to the height of the cylinder, allowing for the thickness of the piston, provided that both arms of the beam are of equal length; the length of the arm of the handle *Q* is, therefore, equal to half the length to which the piston can be raised.

The *fly-wheel X* serves to maintain uniformity in the motion of the engine. Even if the pressure of the steam upon the piston were quite invariable, it could not equally contribute to the revolution of the handle in all its positions. Indeed, we may consider the pressure acting by means of the connecting rod *P* upon the handle, as divided into forces at right angles to each other, the one acting in the direction of the handle itself, as pressure upon the axis does not contribute to produce revolution; this is brought about entirely by the force acting tangentially to the curve of the handle. The amount of these forces varies at every moment. When the arm of the handle stands vertically, every pressure proceeding from the piston acts solely and alone as pressure upon the axis of the curved handle. If the engine were to be brought to a stand-still in this position, the greatest pressure applied to the piston would be unable to set it in motion; the only reason, therefore, that the engine does not remain absolutely motionless on coming into this position is, that the individual parts of the engine continue their motion by virtue of the inertia, in the same manner as a pendulum moves on by virtue of its inertia when arrived at its position of rest. When once the curved handle has passed its vertical position, that portion of the pressure transmitted by *P*, and which occasioned the revolution of the handle, is increased more and more, and attains its maximum when the arm of the handle is directed horizontally. The force, therefore, which turns the handle varies constantly, becoming null twice during one complete revolution, both when the arm of the handle attains its highest and its lowest position; and, in like

manner, it twice attains a maximum. If we examine the motion produced by so variable a force, we shall easily see that it can only be alternately accelerated and retarded. If the circle represented in Fig. 481 exhibit the path described by the handle, we

FIG. 481.



shall perceive that an acceleration of motion will take place from *b* to *d*, because here the moving force will act with the greatest energy. The motion accumulated, as it were, in the parts of the machine must, however, diminish as the arm of the handle moves from *d* to *f*, because the moving force has in the mean time become very weak, and even absolutely null, and thus a retardation is caused of motion by these hinderances; on the way from *f* to *h* it is again accelerated, and again retarded from *h* to *b*.

These alternations in the motion of the curved handle lie in the nature of things, and cannot be wholly avoided. The differences between the greatest and the least velocity become, however, smaller in proportion to the magnitude of the inert mass to be moved; by means of a sufficiently large balance wheel, we may render these differences in the velocity of revolution so inconsiderably small, as to exercise no further injurious influence. The force acting on the part from *b* to *d*, and more strongly from *f* to *h*, cannot effect any marked increase of velocity, as it must move a very considerable inert mass; as, however, a considerable quantity of motion is accumulated in the balance wheel, the decrease in the quantity of motion, as the handle passes from *d* to *f*, or from *b* to *h*, is not sufficiently great to occasion a perceptible diminution of velocity.

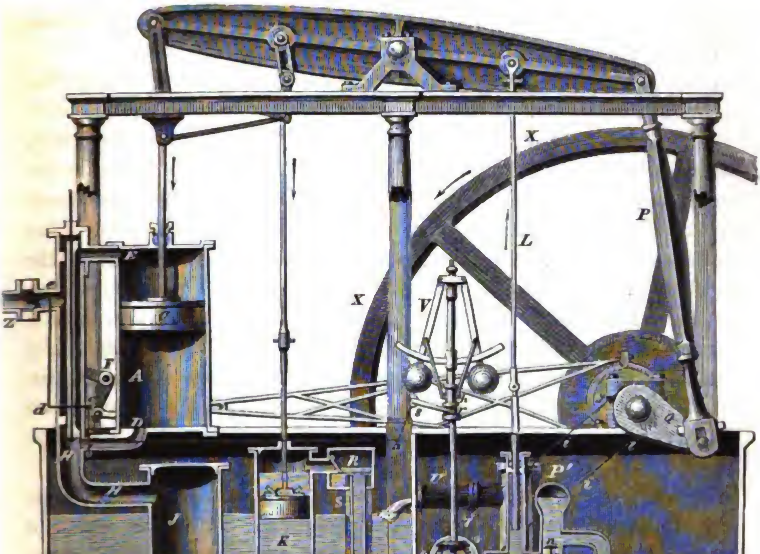
The balance wheel thus equalises the irregularity of motion inherent in the arrangement of the engine. The work which a steam engine may have to perform, be it of what kind it may, never opposes an absolutely uniform resistance to the moving force; and this would occasion irregularity in the working of the whole engine, were it not otherwise rendered uniform by the balance-wheel.

As the work to be performed by the engine, that is, the resistance to be overcome, increases or diminishes, the going of the engine will become quicker or slower. Momentary disturbances of this kind will be equalised by the balance wheel, while an universal diminution of the resistance and the load would be followed, provided the afflux of steam remained the same, by a

continually increasing acceleration in the motion of the engine. In order that the velocity may not exceed certain limits, a valve must be attached to the steam pipe, in order that the ingress of steam may be more or less retarded, according as the valve passes more and more from the horizontal position (that of perfect aperture), to the vertical (that of perfect closure). The turning of this valve must, however, be effected by the engine itself, and this is done by means of an apparatus termed the *regulator*.

A somewhat tense string *i* passes round the rotating axis of the balance wheel over a vertical wheel *o*, Fig. 482, in such a

FIG. 482.



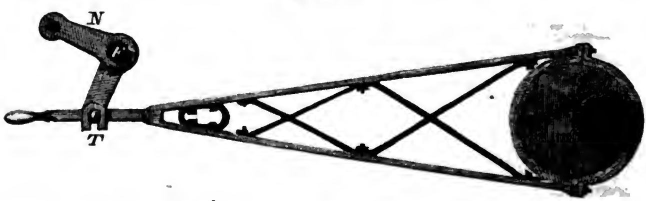
manner that the wheel *o* is made to rotate by the revolution of the principal axis. A vertical conical wheel is fastened to the axis of the disc *o*, whose teeth work into a similar wheel placed horizontally, and which is thus made to rotate on its vertical axis. This axis is prolonged into a rod, to the upper end of which the conical pendulum *V* is attached.

The pendulum *V* consists of two heavy balls so fastened to the upper end of the vertical rod that by its rapid rotation the balls fly apart, owing to their centrifugal force. The rods to which the balls are attached are connected by means of a nut *h* surrounding the vertical rod. The nut *h* is raised up as soon as the balls fly apart; and by this motion of *h* the angular lever *r s a* is turned round the axis *s*, the rod *a b* drawn towards the right side, by which the angular lever *b c d* is turned round the axis *c*, and the rod *e d* thus finally drawn down; but as *e* is the extreme point of a lever arm, the rotating axis of which is the axis round which the valve moves in the tube *Z*, the valve is closed by this point *e* being drawn down. The whole lever system of which we have been speaking here is only represented in outline in our Figure, it being placed on the front side of the engine, and, therefore, really not visible from the point of view in our sectional delineation of the engine.

The working of the cross-cock, or the raising and lowering of the sliding valve, in short, the motion of the apparatus which serves to conduct the steam alternately to the upper and lower part of the cylinder must be effected by the engine itself. The instrument by which this motion is produced is designated the *governor*.

The most important external portion of the *governor*, is the *eccentric disc*, indicated in our Fig. 482 by the letter *y*. This is a circular metallic plate fastened to the axis of the fly-wheel, whose central point does not, however, correspond with the central point of revolution, as may be more plainly seen in Fig. 483. During

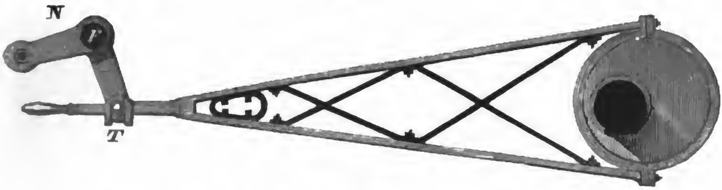
FIG. 483.



every revolution of the axis the central point of the eccentric disc describes a circle. A ring passes around the circumference of the eccentric disc, prolonged towards the one side into a rod, whose end fits at *T* into a lever arm revolving round a fixed axis *F*. The distance of the centre of the eccentric disc from *T* varies, as

the lever arm $F\,T$ passes, and returns to the position seen in Fig. 484, during each entire revolution of the main axis; the

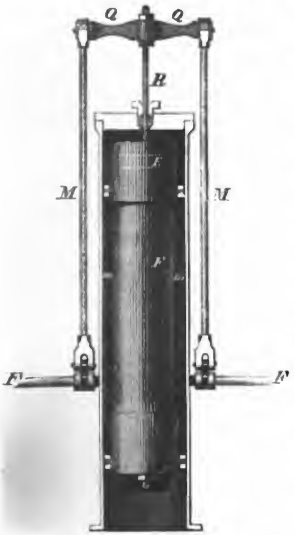
FIG. 484.



chord of the one described in this manner by the point T is, however, evidently equal to the diameter of the circle described by the central point of the eccentric disc.

The axis of F passes through the whole width of the machine, as may be plainly seen in Fig. 485, where this axis is represented at its full length. To this axis are attached two perfectly equal and parallel lever arms N, on either side of the receiver, in which the sliding valve is inclosed. Fig. 483 exhibits only one of these in its true form, while both are seen foreshortened in Fig. 485. To each of these lever arms a vertical bar M, directed upwards, is secured, being connected at the top by a horizontal transverse bar Q, supporting in its centre the bar R, to which the sliding valve is attached. This rod passes, air and steam-tight, through a stuffing-box into the receiver of the sliding valve. The motion of the lever N produces, by means of the rods M, an alternate raising and lowering of the transverse rod Q, by which the sliding valve is also raised up and down.

FIG.. 485.



Let us now consider the influence exercised by the removal of the condenser. If the steam act on the one side of the piston with a force of tension of one atmosphere, while the part of the cylinder lying on the other side is in connection with the air, and not with the condenser, the pressure of the steam on the one side

of the piston will be equal to the pressure of the atmospheric air on the other side, and, consequently, there can be no motion. In order to produce this, it is necessary to raise the force of tension of the steam. Provided this have been made equal to the pressure of two atmospheres, the effect will be precisely the same as if there were a vacuum on the one side of the piston, while the steam pressed upon the other side with the force of tension of one atmosphere; the half of the effective power of the steam being thus lost in overcoming the resistance of the air. If the moving steam had actually a force of tension equal to 3, 4, 5, &c. atmospheres, $\frac{1}{3}$, $\frac{1}{4}$, or $\frac{1}{5}$, &c. of this power would be lost in overcoming the resistance of the air if there were no condenser. The greater, therefore, the force of tension of the steam acting in the engine, the less will be the loss of power in overcoming atmospheric resistance where there is no condenser. If, therefore, the steam that is to move the engine has only a force of tension equal to one atmosphere, or but a little more, a condenser will be indispensably necessary; if, however, the force of tension of the effective steam be greater, the engine may act without a condenser, the advantage of which will diminish in proportion to the increase in the force of tension of the moving steam. The resistance which has to be overcome in the moving of the condensing pump (air-pump), exhausts, however, also a portion of the power of the steam. Thus, at a certain amount of steam pressure the advantages afforded by the condenser are again counteracted by the resistance of the air-pump; and, consequently, in this case it is quite immaterial whether or not we use a condenser. In engines worked by steam of still stronger force of tension, the condenser is more disadvantageous than the contrary, and in such apparatus it is, therefore, wholly omitted.

Such steam engines as are worked with a condenser are called *low pressure engines,* while those that have no condensers are termed *high pressure engines.*

High pressure engines are more simple in their construction than those of low pressure, owing to the absence of a condenser and air-pump, and the former may be used of much smaller dimensions than the latter, and yet produce the same result; for the combined pressure of steam having a force of tension equal to 4 atmospheres acting upon a surface of 1 square foot, is as great as the combined pressure of steam with a force of tension equal to

FIG. 486.

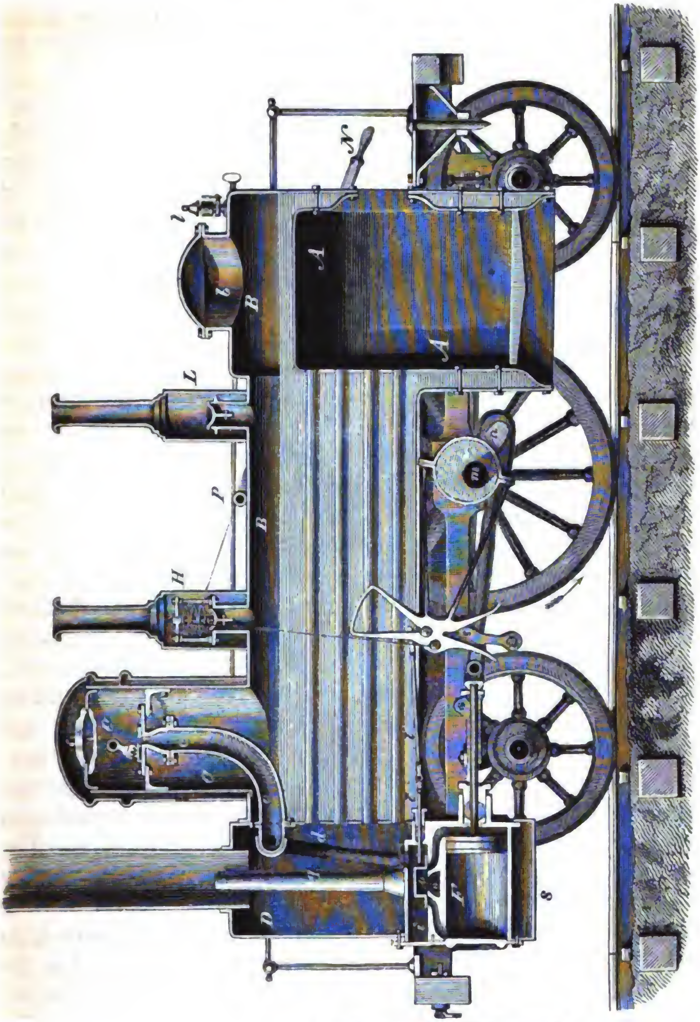
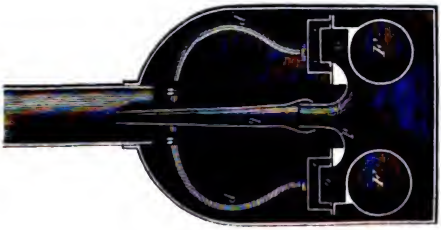


FIG. 487.



H H

1 atmosphere acting upon a surface of 4 square feet. From these causes, high pressure engines are used wherever it is desirable to use an engine of considerable force in a small compass.

One of the best known and most interesting high pressure engines is the *Locomotive* used on railroads. See Fig. 486. *A* is the furnace: the fuel is thrown upon the grate through the opening *a*, which may be closed by a door. There is no escape for the heated air from the furnace, excepting through a series of horizontal tubes, leading from *A* to *D*; from *D* the heated air passes with the smoke out at the chimney. In Fig. 487 we see how these tubes lie above and beside each other. These tubes are carried through a space filled with water, besides which the furnace itself is enclosed on all sides by water. From the extraordinarily large surface with which the water is in this manner brought into contact, a considerable quantity of steam is formed at every moment. The steam is collected over the water in the space marked *B* and *C*; and from *C* it is carried through the tube *c* to the cylinder. If the mouth of the tube *c* were situated very low down, a large quantity of water would by the violent boiling be mechanically carried into the tube *c*, and from thence into the cylinder. To prevent this, the steam chamber at *C* is elevated. The tube *c* soon branches off into two tubes *d* and *d'*, as may be plainly seen in Fig. 489. In Fig. 488 there is only one of these tubes visible, viz. *d*. Each leads to a receiver *i*, from which the steam enters the cylinder *F*. On either side lies a cylinder as seen in Fig. 489; Fig. 488 exhibits only one, viz., the front one of these cylinders. It is represented lengthwise here, the surface of the section does not, however, correspond with the whole of the remaining figure, but lies in front of it. The cylinders lie horizontally, and the piston, together with the piston rods, passes backwards and forwards in a horizontal position. Two passages run to either end of the cylinder from the receiver *i*, to which the steam is conducted by the tubes *c* and *d*. On the lower side of the receiver *i*, a slide moves backwards and forwards, and forms at the middle a box *o* which opens downwards. The position indicated in Fig. 486 shows both passages closed by means of this slide. If we suppose this to be so far moved to the left, that the passage to the left instead of being closed, opens into the cavity *o*, that to the right will be brought into connection with the steam reservoir *i*; in this position of the slide the steam will enter on the right side into the cylinder *F*, and,

FIG. 488.

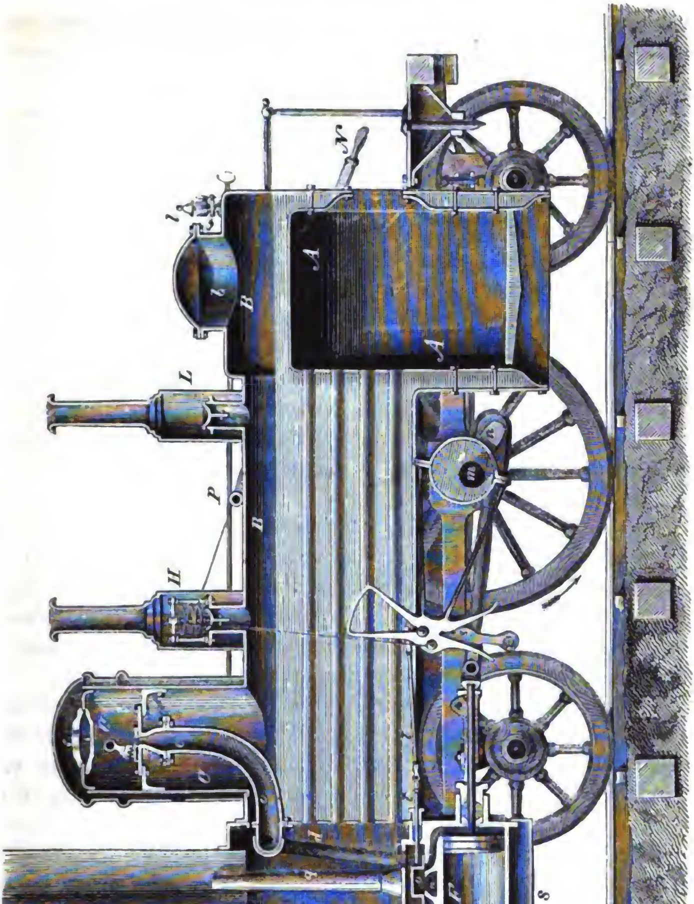
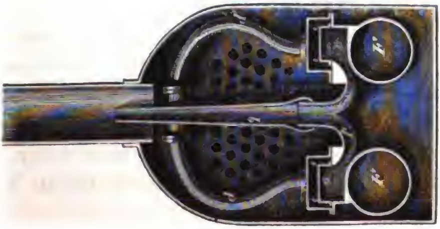


FIG. 489.



consequently, drive the piston to the left, whilst the steam will pass from the left side of the piston through the passage to the left into the box *o*, and from thence to the chimney through the tubes *p* and *q*. If, however, the slide were pushed to the fullest extreme towards the right, the steam would flow from *i* through the passage to the left into the cylinder, escaping on the other side to the right through the passage into the box.

The piston rod is secured by so-called *connecting rods*, that is, it is prevented by this means from deviating from its course, and is thus only able to pass to and fro in the same straight line. To the piston rod is immediately attached the driving rod, which turns the crank *n* round its axis *m*. The middle wheels of the engine are also fastened to the axis *m*, so that by each movement of the piston, a complete revolution of the wheel is effected; thus, at every forward and backward movement of the piston, the engine is propelled a distance equal to the circumference of the middle wheels.

To this axis *m* is likewise attached the eccentric disc, by which the slide in the receiver *i* is moved. As may be seen in our Figure, the × shaped extremity of the rod fastened to the ring of the eccentric disc grasps the upper part of the lever, whose fulcrum is at *s*. By the motion of this lever, the bars *t* fastened to it are moved to and fro, and with them the slide.

By the raising of the lever *N*, the × shaped extremity of the bar is pressed down, and a retrograde motion thus imparted to the locomotive, but here we must end our description, as we are unable to pursue it in detail. *H* and *L* are safety valves, *l* is the steam whistle.

The effect which a steam engine is capable of producing, that is, the power of the machine, depends upon the quantity of water which in a given time can be converted into steam in the boiler; let us, therefore, examine into the action which a litre of water can produce when converted into steam. If we assume that the surface of the piston is 1 square decimetre, and the height of the cylinder (the height to which the piston can be raised) is 10 decimetres, the contents of the cylinder will be 10 cubic decimetres, or 10 litres; in order, therefore, to drive the piston to the top, 10 litres of steam must pass from the boiler into the cylinder. If now the steam has a force of tension equal to 1 atmosphere, the pressure exercised upon every square centimetre of the surface of the piston is about 1 kilogramme,

and the combined pressure upon the whole piston, consequently, 100 kilogrammes; if, therefore, there existed no impediments to motion, we might load the piston with 100 kilogrammes, and this weight would be lifted 10 decimetres, if we conducted 10 litres of steam at 100^0 into the cylinder. The effect, therefore, that can be produced by 10 litres of steam at 100^0, is capable of raising 100 kilogrammes to the height of 10 decimetres, or of raising 1000 kilogrammes to a height of 1 decimetre. A litre of water yields, however, 1700 litres of steam at 100^0; with 1 litre of water, therefore, when converted into steam, we may produce an effect capable of raising 170,000 kilogrammes to the height of 1 decimetre.

In order the better to calculate the power of an engine, it is usual to compare them with *horse-power*. If we assume that one horse is able to raise 750 kilogrammes to the height of 1 decimetre in one second of time, (the best observations on the labour of horses, and the profitable application of their powers, yield a result equivalent to the above-named), we should say, that an engine, in which sufficient steam was formed every second to raise 750 kilogrammes to the height of 1 decimetre, (or 534 lbs. to the height of 1 foot,) was a *one-horse power engine*.

But the steam obtained from 1 litre of water will be capable of raising 170,000 kilogrammes to the height of 1 decimetre; if, therefore, 1 litre of water be converted into steam in the boiler in $\frac{170,000}{750}$, consequently in 226 seconds, the total effect which the steam in this engine can produce, is equal to *one-horse power*. A machine of this kind consumes, therefore, about 15 litres of water in an hour.

All the mechanical power of steam cannot, however, be reckoned as available. Much is lost owing to the piston not acting in an absolute vacuum, to the friction of the piston to be overcome, and the number of pumps that must be set in motion, &c. All these resistances diminish the available effect of the machine to almost the half of the calculated power.

Great advantage has been obtained in the high-pressure engines by the application of the expansion of the steam in the cylinder, which is effected by cutting off the afflux of steam from the boiler into the cylinder, when the piston has traversed $\frac{1}{2}$, or $\frac{2}{3}$, &c., of its course. That a greater effect can be produced with an equal expenditure of steam by the application of the principle

of expansion, may be perceived by the following simple considerations.

If, during the whole time in which the piston is rising, steam pours into the steam cylinder, (as is generally the case in ordinary engines), having a power of tension, which we will assume to be equal to 2 atmospheres, the whole cylinder, when the piston is quite raised, will be filled with steam having a power of tension equal to 2 atmospheres; and during the time the piston is being raised, there will be a mechanical effect produced, which we will designate as E.

If now we suffer steam of double the force of tension, that is, equal to 4 atmospheres, to enter the cylinder, the pressure against the piston will be twice as great, and the mechanical effect E will be produced when the piston is only half raised; that is, when it reaches the middle of the cylinder. If at this moment the further afflux of steam to the cylinder be prevented, the piston will continue the rest of its course, whilst the pressure acting upon it will diminish by degrees to the half; and when it reaches the end of its course, the force of tension of the steam will still be equal to 2 atmospheres.

Since during the first half of the ascent of the piston, the mechanical effect E is already produced, then the whole effect which the steam produces during the second half of the piston's ascent while so expanding, that its tension diminishes from 4 to 2 atmospheres, may be considered as gain; for the quantity of steam filling the cylinder at the close of the piston's motion is precisely as large as if steam having a force of tension of 2 atmospheres had flowed in while the piston was completing its motion.

The steam is generally cut off by means of a special expansion-slide. In ordinary machines the steam flows from the boiler directly into the chamber, in which the sliding valves move, to admit of the entrance of the steam, first to the one and then to the other side of the piston; we will call this chamber a.

In expansion engines there is usually in front of this, another chamber, b; in the plate between b and a there is an opening, through which the steam passes from b to a; this opening can be closed at the proper times by a second slide at b. The motion of this expansion-slide is effected by a properly placed eccentric disc in the same manner as the motion of the sliding valves.

The conversion of fluids into gaseous bodies is commonly termed *evaporation.* Liquids can either be evaporated by boiling, when vapours are formed throughout the whole mass, or by exhalation, when the formation of vapour is limited to the surface of the liquid.

On observing the boiling of a liquid, we generally see a more or less energetic motion pervading all the particles; but if the liquid be boiled in a glass vessel, we may observe bubbles of steam formed at the warmer sides of the vessel and rise to the top. Although at first small, they soon increase in volume as they rise. The bubbles succeed each other most rapidly at the hottest parts of the side. In order that bubbles may be formed in the liquid, which exercises a pressure upon them from all sides, the steam expanding them must have a force of tension equal to the pressure surrounding them. The first condition of boiling is, therefore, that the temperature be sufficiently high to enable the force of tension of the steam to sustain the pressure acting from all sides upon the bubbles of steam. A second condition is, that sufficient heat be present to be absorbed as latent heat during the formation of steam.

From the first condition, it follows that the boiling point of a liquid varies with the pressure on it; and from the second, that the rapidity of boiling depends on the amount of heat which can be conveyed in a given time through the sides of the vessel to the liquid.

At the level of the sea, and at the mean pressure of 760^{mm}, pure water boils at 100^0; on the summit of Mont Blanc, at an elevation of 4775 meters, where the pressure of the atmosphere amounts only to 417^{mm}, water boils at a temperature at which the force of tension of steam is 417^{mm}; that is, at about 84^0. At still greater elevations, water would boil at lower temperatures. If we have a table of the force of tension of the vapour of a liquid, we may easily find the temperature of the boiling point at a given pressure; for it is the same degree of temperature at which the force of tension of the saturated vapour is equal to that pressure. We may, conversely, bring a liquid at any given temperature to the boiling point, by sufficiently diminishing the pressure.

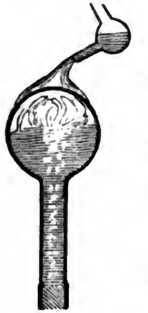
At a pressure of 30^{mm}, for instance, the boiling temperature of water is 30^0, because at this temperature the force of tension of

the saturated steam is 30^{mm}. Under a pressure of 10^{mm} water boils at 11^0, and under a pressure of 5^{mm} at 0^0.

The truth of these data may be shown by experiment. Water at 30^0 must be put in a glass vessel under the exhausted receiver of the air-pump: after a few strokes of the piston the barometer guage will shew a pressure only of 30^{mm}, and the boiling will then begin with the same energy as if the water stood in the open air over a hot fire. This boiling, however, will soon cease, because the receiver will be filled with steam, which will press upon the liquid; another stroke of the piston will soon remove this steam, and cause the boiling to recommence. It is not possible in our air-pumps to make water boil at 0^0, as no rarefaction of 50^{mm} can be produced, owing to the continual re-formation of steam on the surface of the water.

In the apparatus seen in Fig. 490, we observe an analogous, but still more striking phenomenon. A balloon with a long neck *a* is half filled with water; when, by the boiling of the liquid all the air has been driven out, the neck is closed by a cork, and the balloon inverted, as seen in Fig. 490. When left to itself we perceive no ebullition, but as soon as cold water is poured upon the part, the water begins to boil with energy. This is owing to the steam being condensed in the upper part of the balloon, and the pressure on the liquid being thus diminished.

FIG. 490.



The variations in the boiling point have been confirmed by direct experiments made at elevated districts in the Alps, the Pyrenees, and other mountain ranges.

Boiling water is consequently not equally hot at all places on the earth, and, therefore, not everywhere alike applicable to domestic purposes, and the preparation of food. At Quito, for instance, water boils at 90^0, and this temperature is too low for boiling many substances which require a temperature of 100^0.

As the barometer constantly varies at one and the same place, it follows that the boiling point varies also.

If we increase the pressure on fluids, we find that their ebullition is retarded, and we may even prevent this entirely if we make the pressure sufficiently strong. This is the case with the apparatus known by the name of *Papin's Digestor*, see Fig. 491. By means of

FIG. 491.

this, water may be heated to a very high temperature without boiling. The apparatus consists of a cylindrical vessel of iron, or still better, of brass or copper, the sides of which are capable of sustaining a very considerable degree of pressure. The opening is provided with a safety-valve, which can be closed and loaded, so that it shall require a pressure of from 40 to 50 atmospheres to raise it. Boiling is rendered impossible, as the steam which is above the liquid is unable to escape, and consequently exercises a sufficiently strong pressure to prevent it. As soon as the valve is opened, the steam issues with great force; the temperature of the vessel falls, however, simultaneously, as all the heat which had been combined is given off at once by the energetic formation of steam.

This digestor was invented in the middle of the 17th century by *Papin,* a learned man, residing at Marburg and Cassel. It served for a number of remarkable experiments, partly to prove the mechanical force of steam, and partly to show the solvent force of water when heated above 100^0. People learnt with astonishment that as nutritious a substance might be drawn from bones as from the most juicy portions of the muscle.

On causing water to boil in a vessel from which the steam can only escape through a proportionately small opening, we observe an elevation of the boiling point. All the steam that has been formed by the heat passing every moment into the liquid can only escape through a small opening, if a greater rapidity of motion has been imparted by the greater force of tension of the steam.

Not only the steam pressing upon the surface of a liquid mass, but likewise the weight of the column of liquid acts upon the particles in the interior. If, for instance, we had a boiler filled to a height of 32 feet with water, a pressure of 2 atmospheres would act upon the bottom, and here, consequently, steam-bubbles would be formed at a temperature of $121,4^0$. But as the temperature of the liquid mass on the surface cannot rise above 100^0, the liquid will constantly ascend from the bottom, owing to its lesser specific weight. As the pressure decreases with the ascent, steam-bubbles are formed; but their temperature decreases, however, from 121^0 to 100^0. These bubbles, which are formed at the bottom of the vessel, increase in size as they rise, owing to the pressure acting upon them becoming continually less. These phenomena may be

observed even in small vessels, in which the water only amounts to a few inches in depth. Before perfect ebullition has been established, bubbles of steam are formed at the bottom; which, however, are condensed on their ascending, owing to their entering layers of water whose temperature is too low. Hence arises the peculiar sound which we perceive some minutes before perfect boiling has commenced. On making the experiment in a glass bulb, we may observe how bubbles are formed at the bottom, how they ascend, and then disappear; and we then say the water *sings*. This singing is a sign that the water will soon be in a state of perfect ebullition.

Boiling is likewise retarded by substances which are dissolved in the water; thus a saturated solution of common salt brine boils at $108,4^0$, a solution of saltpetre at 116^0, a saturated solution of acetate of potass at 169^0, of nitrate of ammonia at 180^0.

Evaporation is the term applied to the formation of vapour on the free surface of a liquid; whilst, as we have seen, *ebullition* consists in vapour being formed in the interior of the liquid mass. Water evaporates from the surface of rivers, lakes, and seas, and the surface of the damp ground and plants. The vapour has here evidently too inconsiderable a force of tension to overcome the pressure of the atmospheric air. Daily observation shows us that vapour is formed at every degree of temperature, and that it distributes itself through the air even at the weakest degree of tension. It was formerly assumed that a chemical affinity existed between the molecules of the air and those of vapour was the cause of this phenomenon; we have seen, however, that there is no need of having recourse here to chemical forces. The steam of water, be its force of tension ever so inconsiderable, mixes with the air the same as two gases mix. The only condition necessary, therefore, for the evaporation of a liquid is, that the surrounding layers of air be not saturated with vapour; as further, in the mixture of two gases, the molecules of the one form a mechanical impediment to the distribution of those of the other, the air acts as a hinderance in evaporation to the rapid dispersion of the vapour. In a perfectly calm atmosphere, therefore, evaporation goes on very slowly, whilst it progresses rapidly in an agitated state of air, the liquid then comes continually into contact with new layers of air, that are not saturated with vapour. Hence it happens that water evaporates very quickly when a dry wind is in rapid motion.

Latent heat of vapours.—When a liquid evaporates, it must

absorb heat; this absorbed heat is as imperceptible to the feelings and the thermometer as the heat which becomes latent by fusion.

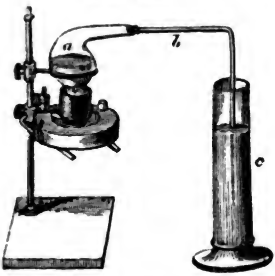
That heat is latent in the formation of vapour, is proved by the temperature of the liquid remaining unchanged during ebullition. The temperature of boiling water remains at 100^0, however much we may increase the fire; all the heat which is added to the boiling water serves only to convert water at 100^0 into steam at 100^0.

The absorption of heat during the evaporation of liquids may easily be rendered perceptible to the feelings. On pouring but a few drops of an easily evaporable liquid, as spirits of wine, sulphuric ether, &c., upon the hand, we experience a sensation of cold because the hand has been deprived of the heat drawn away for the evaporation of the liquid. If we surround the bulb of a thermometer with cotton wool, and then moisten the latter with sulphuric ether, the thermometer will fall several degrees.

After having learnt to know the manner in which heat becomes latent in the formation of vapour, it remains to determine the amount of this heat; that is, to ascertain *how much* heat is necessary to convert a definite quantity of a liquid into vapour.

Fig. 492 represents a glass bulb *a*, in which water is kept boiling by means of a spirit lamp; if now the vapour formed be conducted through a glass tube *b* into a cylindrical vessel *c* filled with cold water, the vapour here will be condensed, and, consequently, the heat which was absorbed at *a* in the formation of vapour will be again liberated at *c*; the cold water at *c* will be thus gradually warmed, and from the elevation of temperature thus produced, we may determine the amount of the latent heat of vapours.

FIG. 492.

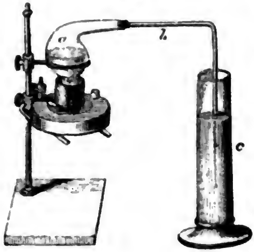


If we assume that, after ebullition has been going on for some time in the vessel *a*, all the air has been wholly expelled, and the end of a crooked tube be then plunged into the cold water of the cylinder *c*, all the bubbles of vapour will at once be condensed as they come into contact with the cold water. In proportion, however, as the water becomes warmer in *c*, the bubbles will likewise become larger, until finally, even if the water at *c* be heated to the boiling point, the bubbles will rise uncondensed through the whole

mass of liquid, and a state of ebullition be established at *c*. At the moment in which ebullition begins at *c*, the experiment will be interrupted by our removing the glass cylinder *c*.

Provided now, that there had been 11 cubic inches of water at 0^0 at the beginning of the experiment, the cylinder at the close of the experiment would have contained 13 cubic inches of water at 100^0, 2 cubic inches of water having been thus added. This additional water has now been evaporated in the vessel *a*, and again condensed in the cylinder *c*; the latent heat which was combined in *a* has become liberated in *c*, and has heated the 11 cubic inches of water from 0^0 to 100^0; the same amount of heat, therefore, which has been absorbed by the evaporation of 2 cubic inches of water was sufficient to raise the temperature of the 11 cubic inches of water from 0^0 to 100^0. But now 2 are to 11 as 1 to 5,5, and we may therefore express the result of our experiment in the following manner: The amount of heat necessary to convert a definite quantity of water from 100^0 into steam at 100^0, suffices to raise the temperature of a mass of water 5½ times greater, from 0^0 to 100^0.

FIG. 493.



We have already stated, that for the unit of heat, that quantity of heat is assumed which is requisite to raise the temperature of 1lb. of water 1^0; to raise the temperature of 5½lbs. of water to the same amount, 5,5 are therefore necessary, and 550 such units of heat to raise the temperature of this mass 100^0.

The latent heat of 1lb. of steam is consequently equal to 550.

The above given experiment is not calculated to determine the latent heat of steam, affording always more or less incorrect results. It is, however, well adapted to show the connection of the matter. The reason of the special want of accuracy attending the results of this experiment is, that at the high temperature to which water must be raised in the cylinder *c*, a considerable loss of heat is experienced by all that surrounds it; a not inconsiderable amount of steam is condensed in the tube, giving off to the air heat that is set free, and which comes to the cylinder *c* as water. We may, therefore, easily understand, that until the water in *c* is made to boil, more water will pass over from the vessel *a* than would be the case if these two sources of error were not present; hence this

experiment is of little value in giving the latent heat of steam. We cannot here enter more fully into the consideration of the more precise methods in use for ascertaining this amount.

In distillation, the vapours formed in any vessel by heat are conducted into a pipe surrounded by cold water, and the vapour is converted into a liquid state; the temperature of the cold water, is, however, considerably raised in the heat liberated by the condensation of the vapour. This may be easily shown by means of a small still, (Fig. 494), in which the vapour is conducted from the glass bulb in which it is formed, into a straight tube, passing through a wider one, which contains the cold water.

FIG. 494.

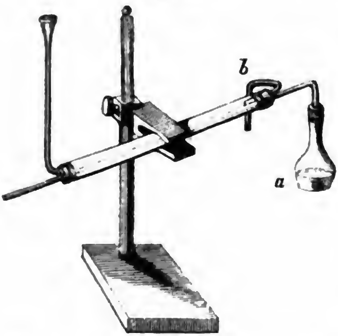
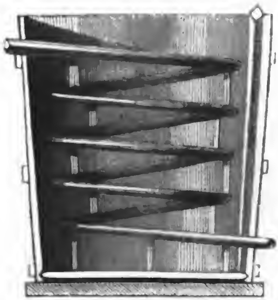


FIG. 495.



The cold water, which enters the condensing tube, flows forth from the other end heated. In distillations conducted on a large scale, the tube in which the vapour is condensed has the form of a helix, and is conducted through the vessel filled with the cold water, as seen in Fig. 495, in order that the vapour may remain as long as possible in contact with the cold water, and that we may be quite sure that no vapour will escape from the open end of the tube in an uncondensed state. When an apparatus of this kind has been in operation for some time, we shall always find the upper layers of the water in the refrigerator very hot, owing to the heated water constantly rising to the surface.

We might determine the value of the latent heat of vapours by any distillatory apparatus, if it were possible every time accurately to calculate the amount of vapour condensed in a given time, and the quantity of heat yielded by it to the cold water;

in order, therefore, accurately to determine the latent heat of vapours, it is only necessary to construct an apparatus in such a manner as to enable us to obtain these amounts with exactitude. According to this principle the latent heat of the vapours of different liquids has been ascertained. Thus—

The latent heat of steam is	.	540
,, ,, vapour of alcohol	.	214
,, ,, Sulphuric ether	.	90

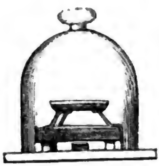
That is to say, in order to convert 1lb. of these liquids into vapour under the pressure of one atmosphere 540, 214, or 90 times as much heat is combined as is necessary to raise the temperature 1lb. of water 1^0.

The latent heat of vapours is not the same for all temperatures, being greater for low, and less for high temperatures.

Production of cold by evaporation.—If a liquid boil in the open air, it will retain a constant temperature, owing to its constantly receiving as much heat through the sides of the vessel as is absorbed by the formation of vapour. But when ebullition goes on under the air-pump, the temperature continually falls, because the vapour withdraws from the fluid itself, and from the surrounding bodies, the latent heat necessary to its formation. The following experiments may be explained by the absorption of heat which takes place in rapid evaporation.

Freezing of water in a vacuum.—We place under the receiver of the air-pump a broad glass dish filled with sulphuric acid. A few inches above it is a thin flat metallic capsule as seen in Fig. 496, containing a few grammes of water. This capsule is generally suspended by three threads, or is made to rest upon three fine metallic feet, which stand upon the edge of the lower glass vessel. A few minutes after the air has been as much as possible exhausted, we see ice needles upon the capsule, and after a time the whole mass becomes solid. This remarkable experiment was first made by *Leslie*. The sulphuric acid absorbs the steam as soon as it is formed, and thus maintains a rapid evaporation. All bodies that absorb steam with energy produce the same action. The metallic capsule ought to be extremely thin, in order, likewise, to take part in the cooling, and must be

FIG. 496.



insulated from the surrounding part by means of bad conductors, so that none of the external heat may be conveyed to the water.

In *Wollaston's Kryophorus* water likewise freezes by its own evaporization. Two glass bulbs, Fig. 497, are connected by a tube. A little water is poured into each bulb, and by its boiling, all the air is driven from the apparatus. When this is done, the aperture at *e* is fused by the blow-pipe, and the whole thus rendered air-tight. If now, all the water be suffered to flow into one bulb, while the other is plunged into a freezing mixture, the condensation of the steam constantly going on in the other bulb will occasion so rapid an evaporation as to cause the water to freeze.

FIG. 497.

Water may also easily be made to freeze by the evaporation of sulphuric ether. For this purpose a glass tube, 1 line in width, is enclosed in cotton wool moistened with sulphuric ether. The tube thus prepared is placed in any kind of glass vessel, and put under the receiver of the air-pump. On exhausting the air, the ether is so rapidly evaporated that the water freezes.

Freezing of Mercury.—We may carry cooling by evaporation down to the freezing point of mercury. To effect this we surround a thermometer bulb with a sponge, or other porous tissue, which must be moistened with sulphuret of carbon, or still better, with liquid sulphurous acid. Evaporation goes on so rapidly, and the amount of heat abstracted is so great, that the thermometer falls to — 10^0 — 20^0, or even 30^0, and the mercury in the bulb freezes after the lapse of a few minutes.

A liquid evaporates more rapidly, consequently generates a greater degree of cold during its evaporation, in proportion to the lowness of its boiling point; on this account a greater degree of cold is produced by the evaporation of sulphuric ether than by water, more by sulphurous acid than by ether, and, finally, still more by liquid carbonic acid than by sulphurous acid.

CHAPTER III.

SPECIFIC HEAT OF BODIES.

Means of comparing quantities of heat.—We assume as a self-evident principle, that the same quantity of heat must always be required to produce the same effect. If, for instance, 1lb. of iron at 10^0 have, from any cause, been heated to the temperature of 11^0, the same quantity of heat must always be required, whether the source be the sun, or a fire; or whether it reach the iron by contact, or by radiation. In like manner, the same amount of heat will always be required to fuse 1lb. of ice at 0^0, and a definite quantity to evaporate 1lb. of water at 100^0. The quantities of heat must, however, also be proportional to the weight of the substances on which they act, in order to produce a definite effect; that is, to raise the temperature of 100lbs. of iron, from 10^0 to 11^0; and, in order to fuse 100lbs. of ice, or evaporate 100lbs. of water, a hundredfold greater amount of heat is necessary, than is required to produce the same effect on 1lb. of these substances.

A substance has a greater or lesser *capacity* for *heat*, according as a greater or lesser quantity of heat is required to produce a definite change of temperature, or an elevation of temperature of 1^0; this requisite quantity of heat is termed the *specific heat* of the substance. Two bodies have equal capacities of heat, if of equal weight, they require the same quantity of heat to raise their temperature 1^0; on the contrary, the capacity of heat of a body is 2, 3, or 4 times greater than that of another, if it require a 2, 3, or 4 times greater quantity of heat.

One and the same body may have a *variable capacity for heat*; as, for instance, is the case with platinum, which requires a greater amount of heat to be heated from 100^0 to 101^0, than to raise its temperature from 0^0 to 1^0. The capacity of water for heat is *constant*, on which account this liquid has been chosen as the unit.

From these definitions it follows, that a body, whose weight is m, and whose capacity for heat is c, will, at an elevation or depression of temperature of t^0 receive or lose an amount of heat, ᵉ product of which may be expressed by $m\ c\ t$.

In order to determine the specific heat of bodies, three different methods have been pursued, viz., that of the fusion of ice, mixtures, and cooling.

According to the first method, the body whose specific heat is to be determined is weighed, heated to a definite temperature, and placed in a vessel filled with pieces of ice. While it cools, a part of the ice is fused, and from the quantity of water, we obtain the quantity of heat lost by the body, and hence, consequently, its specific heat.

The cooling method is based upon the following principle. If a heated body be brought into a space in which it can only cool by radiation, it will, if other circumstances remain the same, cool slower in proportion to the amount of specific heat.

The method of mixtures affords the most accurate results, and must, therefore, be somewhat more attentively considered. This method consists principally in this, a weighed quantity of the body to be examined is heated to a certain temperature, and then plunged into a vessel with water, the temperature of which has been raised by the cooling of the body; if we know the quantity of the cold water, we may ascertain the elevation of temperature sustained by it from the cooling of the immersed body, and thus the specific heat of the latter may be computed.

If we assume that a platinum ball weighing 200 grms. warmed to 100^0 has been immersed in a mass of water of 105 grms. at 15^0, and has raised its temperature by its own cooling to 20^0, that is, has heated the water 5^0, it is clear, that the 200 grms. of platinum must be cooled down to 80^0, in order to heat 105 grms. of water 5^0. The same amount of heat that has been yielded by the platinum ball would, therefore, also have sufficed to raise the temperature of 525 grms. of water 1^0. If the platinum ball had only weighed 1 grm., the amount of heat given off by it at a depression of temperature of 80^0 would be able to warm only $\frac{525}{200}$, or 2,625 grms. of water 1^0, or 1 grm. of water $2{,}625^0$. Hence, it follows, that the same amount of heat that raises the temperature of 1 grm. of platinum 80^0 can only raise an equal mass of water $2{,}625^0$, platinum thus requires only $\frac{2{,}625}{80}$, that is, 0,0328 times less heat than an equal quantity of water, to experience an equal variation of temperature; the specific heat of platinum is consequently 0,0328.

If we designate the weight of the cooling water by m, and the elevation of temperature by t, (in the above-given example they were 105 grms. and 5^0), and the weight and depression of temperature of the cooled body as m and t', (in our examples they stood as 200 grms. of platinum and 80^0), it follows from the above-given considerations, for a concrete case, that we have the following formula for the computation of the specific heat c of the cooled body: $c = \frac{m \, . \, t}{m' \, t'}$; that is, expressed in words, we find the specific heat of the cooled body by dividing the product of the weight of the cooling water, and its variation of temperature by the product of the weight of the body and its depression of temperature.

Results of the experiments on specific heats.—The determination of specific heat has acquired much importance in chemistry from the labours of *Dulong* and *Petit*, who found that the product obtained on multiplying the specific heat of an element by its atomic weight was always constant. Thus, for instance, they found the specific heat of iron to be equal to 0,1100, while the atomic weight of the metal was 339,2, and their product is 37,31. If we multiply the specific heat of copper 0,0949 with its atomic weight 395,7, we obtain the product 37,55, a value which agrees almost perfectly with what has been found for iron. In like manner, it was found that this product was almost exactly the same for all metallic elements; it therefore appears, that the principle of the specific heat of metallic elements being inversely proportional to their atomic weight, is well-grounded.

We have thus one means more of learning to know the atomic weight of a body, and to test the value of atomic weights found by other methods. The atomic weights of the elements were not, at the period when *Dulong* and *Petit* carried out their researches, as firmly established as at present; choice had often to be made between many atomic weights for the same body, and *Dulong* and *Petit* naturally selected the one most in harmony with their own law.

Subsequently to that time, atomic weights were more exactly determined in another way; but this, instead of confirming the law of *Dulong*, seemed rather to yield results in direct opposition to those obtained by his method. The most recent investigations of *Regnault* upon specific heat have, however, established the correctness of this law beyond all doubt.

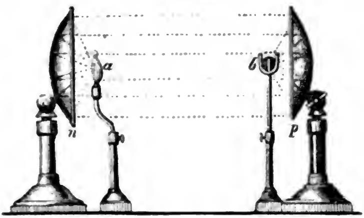
CHAPTER IV.

TRANSMISSION OF HEAT.

Existence of radiating heat.—Radiating heat penetrates certain bodies in the same manner as light passes through transparent bodies; the rays of the sun, for instance, impinge upon our earth after they have traversed the whole atmosphere, and heat the earth's surface whilst the higher regions of the air remain cold; the rays of heat consequently pass for the most part through the atmosphere without being absorbed by it. On approaching the fire of a hearth, we experience a burning heat, and yet the air between us and the fire is not heated to an equal degree, for on holding up a screen this heat instantaneously ceases, which could not possibly be the case if the whole mass of air surrounding us had so high a temperature. Hot bodies can, therefore, emit heat in all directions, which passes through the air as the rays of light through transparent bodies; we therefore speak of *radiating heat*, and *rays* of heat, in the same manner as rays of light.

If two large spherical, or parabolic concave mirrors of polished tin-plate (Fig. 498), be removed about 5 or 6 metres from each other, and so placed that the axes of both mirrors fall upon the same line, and if a piece of tinder be placed in the focus of the one mirror, and an iron ball in a state of white heat, or a burning coal, whose combustion is quickened by a bellows, be laid in the opposite focus, the tinder will soon ignite, as if it had been brought into contact with a fire. This experiment proves that the glowing body radiates heat; for it is evident that the tinder has not been ignited by the intervening layers of air having become by degrees so strongly heated. On removing the tinder from the focus it will not be ignited, even on being brought much nearer to the glowing body.

FIG. 498.



If we put a ball at 300° in the place of the glowing coal, and a common thermometer in the place of the tinder, the thermometer will rapidly rise; consequently, this ball at 300° likewise radiates heat.

If, instead of the hot ball at 300°, we take a vessel full of boiling water, or filled with water at 90°, 80°, or 70°, we may not, perhaps, observe any further elevation of temperature in the thermometer; this, however, does not prove that the walls of the vessel radiate no more heat at this temperature, but merely, that a common thermometer is not sensitive enough for this purpose. More sensitive instruments have, therefore, been made use of, as, for instance, an air thermometer, *Rumford's* or *Leslie's* differential thermometer, or *Melloni's* thermo-multiplicator.

An air thermometer may be constructed for this purpose, somewhat in the manner represented in Fig. 499. A bulb of from 3 to 4 centimetres in diameter is blown at the end of a tube, the bore of which is about 1^{mm}; the tube is bent, as may be seen in the figure, and has in the middle a second bulb, and at its other extremity a funnel, in order to prevent the fluid standing between *c* and *d* from returning into the lower bulb, or running out at the top. When the dimensions of the instrument are known, we may easily compute almost the full degree of its sensitiveness; it cannot, however, be graduated, owing to the fluid remaining exposed to the atmospheric pressure, and owing to the alternate entrance and escape of air from the lower bulb.

FIG. 499.

Rumford's differential thermometer.—Fig. 500 exhibits an apparatus consisting of two glass bulbs, *a* and *b*, connected by a bent glass tube, whose horizontal part is from 5 to 6 decimetres in length. In this tube there is an index of alcohol, or sulphuric acid, pressed upon on each side by the air of the bulbs, and it will consequently only stand in a fixed position when the pressure on both sides is equal. The place occupied by the index when the temperature of both bulbs is perfectly equal, is the zero of the division. If the one bulb be heated more than the other, the index will be driven towards the cooler bulb, and its removal from the zero will be proportional to the difference of temperature of the two bulbs.

FIG. 500.

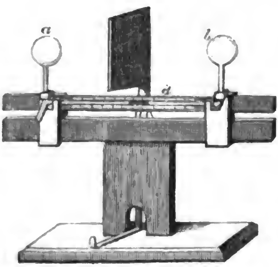


FIG. 501.

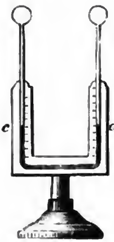
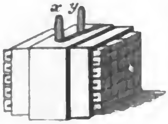


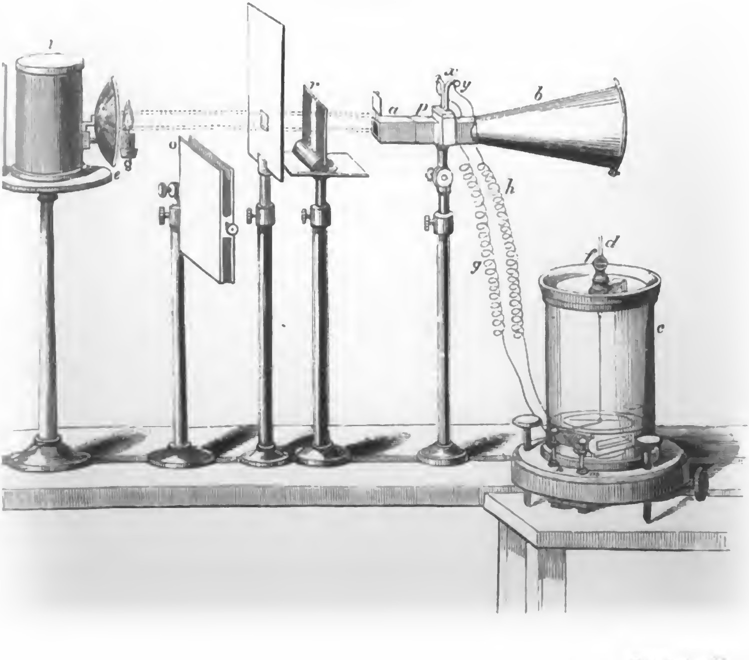
FIG. 502.



Leslie's differential thermometer.—Fig. 501, is constructed in a similar way, with the exception of having somewhat smaller bulbs, and the vertical arms of the connecting tubes being longer, and nearer to each other.

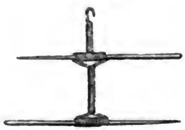
Melloni's thermo-multiplicator consists of a thermo-electric pile, Fig. 502, such as has already been described at page 430, and of a very sensitive multiplicator. The pile is carefully blackened at both ends with soot, and placed, together with its casing, at *p* (Fig. 503) upon a stand; the coverings *a* and *b* serve to keep the currents of air and the lateral radiations from the pile; as the one *b* is conical, it also serves to concentrate the rays of heat from this side, if necessary. The copper wire forming the galvanometer, is 7 or 8 metres long, and

FIG. 503.



is wound 40 times round a metal frame. The well chosen magnetised needles, after having been carefully compensated, are connected together, as seen in Fig. 504. This system is suspended by a cocoon thread, hanging in the centre of a glass bell *c*, Fig. 503. By turning the knob *f*, the cocoon thread may be somewhat raised or lowered, together with the needles. The apparatus must be placed upon a sufficiently strong table, and at a proper level, so that the thread hangs exactly in the middle of the graduated circle, and so directed that the needles point to the zero of the scale, when their plane coincides with the magnetic meridian.

FIG. 504.



The easily expanding wire spirals, *g* and *h*, which are in connection with the two ends of the thermo-electric pile at *x* and *y*, and at *m* and *n*, with the ends of the multiplicator wire, serve to restore the connection between the thermo-electric pile, and the multiplicator. The smallest difference of temperature between both blackened ends of the column causes a deviation of the needle, which may be seen by the graduated scale.

Capacity of bodies to radiate heat.—The capacity possessed by bodies of radiating heat is very dissimilar, and depends essentially upon the condition of the surface; in general the surfaces of the less dense bodies radiate, other circumstances being the same, more heat than the surfaces of bodies possessing a greater density. The irregularity in the capacity of radiation of different surfaces, has been illustrated by *Leslie* in the following manner: he brought the bulb of his differential thermometer into the focus of a concave mirror, and placed at some distance from the axis of a mirror, a hollow tin-plate cube, filled with hot water; the sides of the vessel being from 15 to 18 centimetres in length, and the one lateral side being covered with soot, while the other was polished; when the latter side was turned towards the mirror, the effect was much less considerable upon the differential thermometer than when the blackened side was turned towards it; the surface rubbed with soot, consequently radiated far more heat than the polished metallic surface.

This method is certainly quite capable of showing the difference in capacity of radiation; but to give more exact comparisons, however, *Melloni's* method is far more preferable; he placed at a proper distance from the thermo-pile a hollow cube

of tin plate, the side of which was from 7 to 8 centimetres long, and which was filled with hot water, kept at a constant temperature by means of a spirit lamp; the lateral surfaces of this cube were differently prepared, one being covered with soot, another with white lead, the third with Indian ink, and the remaining one polished. The deviations of the needle were very unequal, as the one or the other side was turned towards the thermo-multiplicator, and from the deviations thus observed, were found without further difficulty, the relation in which the capacities of emission stand to each other for different fluids. In this manner the capacity of radiation has been determined for the following bodies:

Lamp-black .	. 100	Indian ink .	. 85
White lead .	. 100	Gum-lac .	. 72
Isinglass .	. 91	Metallic surface .	12

Thus, if we designate the capacity for radiation in pine soot as 100, that of a polished surface will be equal to 12, consequently, only $\frac{12}{100}$ of the former.

Absorption of rays of heat.—Every body has the power of absorbing more or less the rays of heat which impinge upon it coming from some other body; this is proved in the above-named experiments, for bodies are only heated in the focus of a concave mirror because they absorb the rays of heat concentrated upon them by the mirrors. That this power, however, appertains to all bodies, is proved by their assuming a temperature when exposed to the sun's rays which is higher than the temperature of the air.

The power of absorption is not equal for all bodies, which arises from their not having equal power of emission, for a surface which easily radiates heat must, conversely, also have the capacity for absorbing these rays. This inequality in the power of absorption may be shown by a simple experiment; for instance, if we put a thermometer, whose bulb has been blackened, in the rays of the sun, it will rise much more rapidly than another, whose surface has not been blackened; the blackened surface of the one thermometer bulb absorbs, therefore, evidently more rays of heat than the polished surface of the other.

The rays of heat absorbed by a body are, therefore, the cause of

its becoming heated; and thus, in order to heat a body by radiation as much as possible, it is necessary to cover it with some coating which strongly absorbs rays of heat; for the same reason, thermoscopes, which serve to manifest in a striking manner the actions of the radiation of heat, the bulbs of differential thermometers, and the two ends of the thermo-electric pile are coated over with soot, as this substance has a stronger capacity for absorption than any other, with which we are acquainted.

We have seen above that metallic surfaces possess only a very small power of emission, and hence, it follows, that they are only capable of absorbing rays of heat to a very small degree.

Reflection and diffusion of the rays of heat.—Bodies have in general the capacity of reflecting a portion of the rays of heat impinging upon them in the same manner as they more or less regularly reflect rays of light. The mirrors which were used in the above experiments, furnish us with a decisive proof of the reflection of rays of heat, for they are not themselves heated in the experiment with the tinder. A simple mode of reasoning convinces us that most bodies must possess this capacity for reflection, and that, if we may so speak, it is complementary to the power of absorption, for the sum of the absorbed rays of heat must evidently be equal to the combined whole of the incident rays, provided the body suffer no rays of heat to pass through it. When, therefore, the power of reflection is greater, the power of absorption is smaller, and conversely. A body that reflects no rays of heat must absorb all rays, as, indeed, is the case with such surfaces as are carefully covered with soot; polished metallic surfaces on the other hand, which possess a great capacity of reflection only absorb rays of heat to a very inconsiderable degree.

Rays of heat are reflected precisely according to the same laws as rays of light, that is to say, the angle of reflection is equal to the angle of incidence; this follows from the experiments with the concave mirrors, as the focal points for the rays of heat correspond with those of the rays of light.

As rays of light are irregularly distributed in all directions on the surface of a perfectly polished body, rays of heat likewise undergo a *diffusion* on the surface of most bodies. We may convince ourselves of this by the following experiment. If we suffer the sun-beams to fall through an opening in the shutter of a dark room upon the opposite wall, the luminous spot, which is visible from all directions, owing to its distributing sunlight on

every side, will also distribute rays of heat irregularly, that is, it will throw forth rays of heat in all directions, as if it were itself a source of heat. This diffusion of the rays of heat is rendered manifest on turning the thermo-electric pile towards the bright spot; we shall see the needle deviate at whatever part of the room we place the instrument; and the action cannot, therefore, arise from a regular reflection, while it is evident, that it is not the consequence of a heating of the part of the wall on which the sun's rays have fallen, for the needle will return to the zero of the scale as soon as the aperture in the shutter is closed.

Capacity of bodies to transmit rays of heat.—That solid bodies can transmit rays of heat in the same manner as transparent bodies transmit rays of light has already been proved, by showing that we are able to ignite combustible bodies on holding them in the focus of a lens exposed to the rays of the sun. More accurate investigations could only be made by help of the thermo-electric pile, and *Melloni* has carried out a series of highly interesting observations upon the transmission of the rays of heat through different bodies.

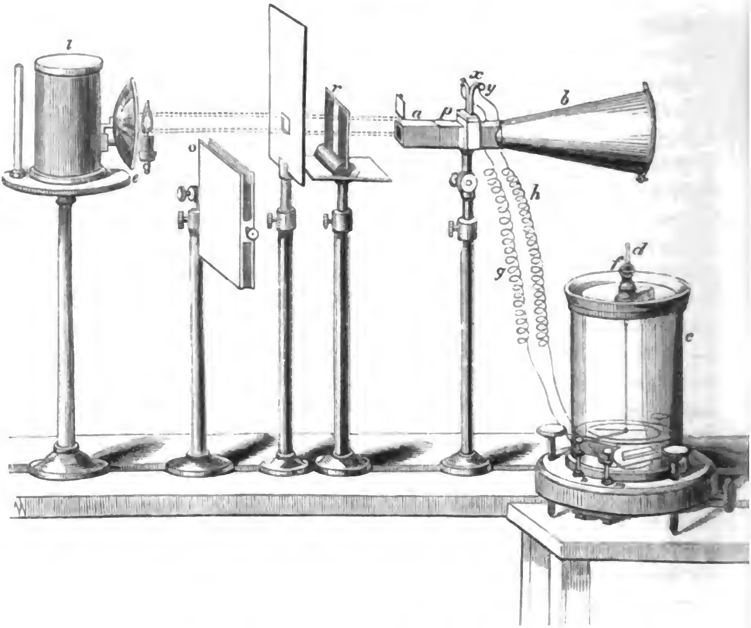
Such bodies as retain rays of heat as transparent bodies retain rays of light are termed by *Melloni*, *athermanous;* and those which are to rays of heat as transparent bodies are to rays of light, are called by him *diathermanous.* Air consequently is a *diathermanous* body; and we shall soon see that many solid and fluid bodies are *diathermanous,* although in very unequal degrees.

The experiments were made in the following manner.

The source of heat, a small oil lamp, for instance, or a hollow cube of tin plate filled with hot water, and blackened on the outside with soot to radiate heat the better, was so placed as to produce a deviation of the needle of 30^0; when the rays of heat were then received upon a plate of the body to be examined, and placed at *r*, Fig. 501, the needle receded sometimes more, sometimes less, and it was thus observed that equally thick and equally transparent plates of different bodies did not transmit equal quantities of radiating heat. If, for instance, the free radiation of the source of heat cause a deviation of 30^0, the needle will recede to 28^0 if a plate of rock salt from 3 to 4 millimetres in thickness be placed at *r*, whilst an equally thick plate of quartz will cause the needle to recede to 15 or 16^0; mineral or rock salt consequently

transmits rays of heat far better than rock crystal. Many less

FIG. 505.



transparent bodies even transmit rays of heat better than those that are perfectly transparent. Whilst, for instance, a wholly transparent plate of alum reduces the deviation of the needle from 30^0 to 3 or 4^0, a far thicker plate of smoky-topaz brings the needle back to 14 or 15^0. Some bodies which are almost wholly opaque, as black glass and black mica, transmit rays of heat tolerably well.

If we suffer the rays of heat that have passed through a glass plate to fall upon an alum plate, they will be wholly absorbed; whilst, however, an alum plate will transmit almost all the rays of heat that had previously passed through a plate of citric acid. This phenomenon has the greatest analogy with the transmission of light through a coloured medium; rays of light that have passed through green glass are, it is well known, easily transmitted

through other green glasses, which are absorbed when suffered to fall upon red glass; the differences between rays of heat are therefore quite analogous to the differences of colour in light.

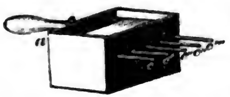
Similar resemblances have been observed in relation to the capacity of emission and absorption of bodies.

Rays of heat are refrangible, like rays of light, as may best be seen by means of a prism of rock salt. Phenomena of polarization have also been shown in rays of heat.

Distribution of heat by conductors.—Heat may pass from one body to another, not only by radiation, but by immediate contact, and may then be transmitted through the whole mass; there is, however, a great inequality in different bodies in relation to the facility with which this is effected; in many, heat is very easily transmitted, whilst in others it passes with much less facility from one particle to another. A match that is burning at one end may be held between the fingers at the other extremity without any elevation of temperature being even felt in the wood; the high temperature of the burning end is not speedily transmitted to the rest of the mass of wood, because wood is a *bad conductor of heat.* An equally long metallic wire made glowing hot at one extremity cannot be grasped at the other end without burning the hand; heat consequently distributes itself from the glowing part to the whole of the rod, metal being a *good conductor*.

We may make use of *Ingenhousz's* apparatus (Fig. 506) to show the inequality of the capacity of different bodies to transmit heat. Many rods made of the substances to be compared are inserted into the lateral wall of a box of tin plate, the rods being all of equal diameter and all covered with a layer of wax; on pouring boiling water or hot oil into the box, the heat will penetrate more or less into the rods and fuse the wax coating. If we assume that one rod is of copper, another of iron, a third of lead, a fourth of glass, and the last of wood, the wax coating of copper will be perfectly fused before the coatings over the other rods are much melted, showing that copper is the best conductor of these five bodies. The fusion of the wax is more rapid over the iron than the lead, and when all the wax has melted off the copper rod, fusion has only progressed to a very small extent upon the glass rod, while scarcely a trace of fusion is perceptible on the

FIG. 506.



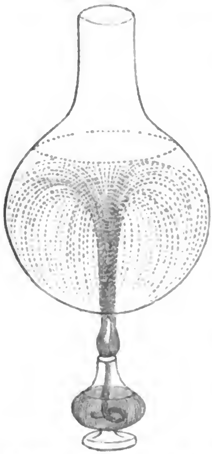
wooden rod; which proves that wood is the worst conductor of heat among these five substances.

Of all bodies, metals are the best conductors of heat; and ashes, silk, hair, straw, wool, &c., and porous bodies especially, are the worst.

In practical life we are constantly making numerous applications of the good or bad capacity of different bodies for conducting heat. Thus, objects that we wish to protect from the cold, we surround with bad conductors of heat: twisting straw round trees and shrubs in winter to save them from the effect of the frost; on the same principle our clothes keep us warm, owing to their being made of bad conductors of heat. We can bring a liquid to a state of boiling much more rapidly in a copper vessel than in one made of porcelain, and having equally thick walls.

Capacity of liquids and gases for conducting heat.—Heat is distributed through liquids principally by currents, which arise from the heated particles rising more rapidly to the surface, owing to their inconsiderable density. These currents may be made apparent by throwing shavings into water enclosed in a glass vessel, and then heating it slowly from below, (Fig. 507), when we shall see the current rise in the middle, and be directed upwards, and turn downwards on either side. On heating a liquid from above, so that the hydrostatic equilibrium is not disturbed, the heat can only be transmitted in the same manner through the mass of the liquid, as is the case with solid bodies; that is to say, by the heat being conducted from one layer to the other. In such cases, heat is only slowly diffused through the mass of the liquid, liquids consequently are bad conductors of heat.

FIG. 507.



In order to convince oneself of the bad capacity of liquids for conducting heat, one need only plunge the bulb of a thermometer into cold water, and then pour hot oil upon the water. The uppermost layers of water will scarcely manifest any elevation of temperature.

Despretz has determined the capacity of liquids for conducting heat, by heating columns of water 1 meter in height and from 0,2 to 0,4 meters in diameter, by continually pouring hot water over them from above. This process was continued for about 30 hours, until the temperature of the columns was settled and stable on all sides. From these experiments it follows that the capacity of water for conducting heat is about 96 times less than that of copper.

The air and gases especially are likewise very bad conductors of heat; but we are unable, owing to the radiation of heat, to ascertain their capacity for conducting heat, by means of the thermometer brought into the different layers of the mass of air to be examined. That gases generally, and the air in particular, are bad conductors of heat, is, however, proved by this: that bodies surrounded on all sides by layers of air can only be cooled or heated very slowly if only the intermixture of the layers of air be prevented. We thus see the utility of double windows and double doors in keeping a room warm. The bad capacity for conducting heat which we perceive in porous bodies, as straw, wool, &c., depends especially upon their innumerable interstices being filled with air. Bodies of which we say that they keep us warm, as, for instance, our clothes, straw, &c., are not warm in themselves, but owe the property they possess to their bad power of conducting heat; if we wrap any of these round ice, they will hinder its fusion, by protecting it from all external heat.

CHAPTER V.

DIFFERENT SOURCES OF HEAT.*

Generation of heat by chemical combinations.—Excepting the sun, chemical combinations furnish us with the most important sources of heat. Almost every chemical process is accompanied by a development of heat.

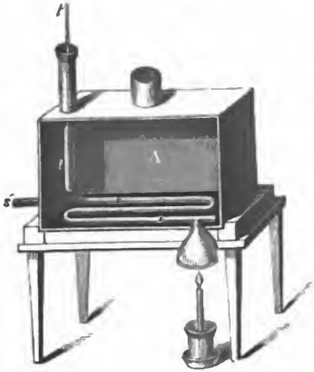
The development of heat induced by combustion, that is, by a rapid combination of bodies with oxygen, is of the greatest importance.

In order to determine the amount of heat developed in combus-

* Thomson's "Heat and Electricity," 2nd Edition, 8vo. 1840.

tion, *Rumford* made use of the apparatus delineated in Fig. 508.

FIG. 508.



The box *A* is filled with water, through which passes a worm tube; the entrance of this tube is formed by a funnel, below which are placed the bodies to be consumed. The experiment is easily made with oil and alcohol, which are poured into a little lamp, which must be weighed at the beginning and end of the experiment, in order to ascertain the quantity of the material consumed. The flame and the products of combustion pass through the tube, and heat the water of the apparatus. From the elevation of temperature experienced by the water, together with the whole apparatus, we may estimate the amount of heat engendered by combustion; but here we must not disregard the heat carried off by the gaseous products of combustion from the tube.

By experiments of this kind the following results were obtained as to the amount of heat developed.

For the combustion of 1 grm. of	The temperature of 1 kilogramme of water may be raised
Hydrogen	36,40°
Olefiant gas	12,20
Absolute alcohol	6,96
Charcoal	7,29
Wax	10,50
Rapeseed oil	9,31
Tallow	8,37

Animal heat.—The temperature of the heat of blood of all animals is almost always different from that of the medium in which they live. The animals of the polar regions are always warmer than the ice on which they live; but in the countries on the equator they are cooler than the glowing air which they inhale. Neither birds nor fish have the same temperature as the air or the water surrounding them; the animal body must consequently have a peculiar heat, which it is constantly able to engender.

The internal heat of the human body appears to be the same for all organs, and to be equal to that, to which a small thermometer rises, when we place the bulb under the tongue and close the mouth until it has ceased to rise; this temperature is about 37^0 C. Age, climate, health, and disease, can but slightly affect it.

The blood heat is greater in birds than in any other animals, amounting on an average to 42^0; the blood heat of the mammalia is very nearly equal to that of man. In birds and the mammalia the blood heat is independent of the temperature surrounding it; but in other species of animals, as the amphibia, fishes, &c., the temperature of the body varies but little from the surrounding medium.

What, then, is the source of animal heat? The air which we inhale becomes changed in the same manner as the air that has served in the combustion of bodies; the oxygen being converted into carbonic acid, and a regular process of combustion being thus carried on in the lungs. Since *Lavoisier* made this discovery, the source of animal heat has ceased to be a mystery. Carbon is brought into the body with the food, and is then combined in the lungs with the oxygen of the inhaled air. By the oxidation of carbon in the animal body, the same amount of heat must, however, necessarily be engendered as if the carbon had been converted by rapid combustion into carbonic acid.

In a cold medium, men and animals constantly lose more heat than in a warmer atmosphere; as, however, the blood heat in the mammalia and in birds is independent of the temperature of the air, it is evident that more heat must be engendered in the body if a greater quantity be withdrawn every moment from it, and more, consequently when the body is in a colder air, than when it gives forth but little heat in a warmer medium. In order, however, to be able to engender more heat in the same periods of time, more carbon must be introduced into the body, by the oxidation of which substance heat is developed: in the same manner as we must consume more fuel in a stove during cold weather than during a less intense degree of cold, in order to maintain a constant and fixed temperature in the apartment. Thus, too, we may understand why the inhabitants of northern countries require to partake of more food, and especially of the kind containing a greater amount of carbon, than is necessary for those who live in hotter zones.

Development of heat by mechanical means.—We have already

stated that heat is liberated by the compression of air; and when this is rapidly effected, a very considerable elevation of temperature may be brought about, on which depends the pneumatic tinder-box. Fluids that do not admit of strong compression show but an inconsiderable elevation of temperature. Solid bodies are often very much heated by compression, as we may observe in the case of hammering metals and striking coins. It has not yet been determined with certainty whether the elevation of the temperature of solid bodies by compression must likewise be ascribed to the circumstance, that their heat is smaller with a greater degree of density and that consequently, a part of the heat, which is maintained in them as specific heat, escapes in a perceptible form on their being compressed.

The considerable elevations of temperature occasioned by friction are generally known. The iron tire of a wheel often becomes so heated that it will hiss on coming into contact with water; dry wood may be ignited by friction, and an iron nail may be brought into a state of white heat on being held against a moving grindstone of 7½ feet in diameter. At the present time we are unable to afford a satisfactory explanation of these phenomena.

*Theoretical views concerning heat.**—We have become acquainted with the most important laws of the phenomena of heat, without having entered upon the question of what *heat* really is.† In this respect, therefore, the theory of heat has been treated precisely in the same manner as the first part of the theory of light, where the empirical laws of reflection and refraction were developed, without anything further being said of the nature of light. We are, however, still deficient in a theory from which the phenomena of heat may be derived, (as the phenomena of light from the wave theory) not only qualitatively, but also quantitatively.

We generally imagine that heat is an imponderable substance, penetrating bodies: and this idea answers very well for many phenomena; as, for instance, the combination of heat, and the capacity for conducting heat, affording us a good representation of these phenomena, the expressions being based upon this view. If, however, the phenomena of the capacity for conducting heat, of latent heat, and of diffusion of heat, accord tolerably well with the idea of a *substance* of heat; it is, on the other hand, very improbable that there are such substances, and more likely that imponderables will all vanish from physics, as has already been the case

* Graham's "Elements of Chemistry," 2nd Edition, 8vo. 1847.

† Thomson's "Heat and Electricity," 2nd Edition, 8vo. 1840.

with respect to light. In the theory of heat, the most important step made, is probably that which corresponds to the introduction of the theory of vibration in the case of light.

There are some phenomena which cannot be reconciled with the views of heat being a substance; for instance, radiation and the generation of heat by friction.

The laws of the radiation of heat are so similar to those of the radiation of light, that we are tempted to ascribe the former likewise to a vibration of ether. If, however, radiating heat were transmitted by the vibrations of ether, perceptible heat must likewise be occasioned by the vibrations of the material parts of bodies.

That the phenomena of heat actually arise from such vibrations, is very probable, although we are not able, even in a satisfactory degree, to explain all phenomena of heat on this hypothesis; and we are still unable to dispense with the idea of a substance of heat in our representations and descriptions.

In order to explain the phenomena of heat by vibrations, we must assume that the temperature of bodies increases with the amplitude of the oscillations; and by such means we may also explain expansion by heat.

The number of the vibrations is increased on the transition from the solid to the fluid, and from the latter to the gaseous condition. An increase in the number of the vibrations is, with an equal amount of motion, alone possible when the amplitude is less; and thus we may explain the combination of heat.

SECTION VIII.

METEOROLOGY.*

CHAPTER I.

DISTRIBUTION OF HEAT ON THE EARTH'S SURFACE.

The heating of the earth's surface, and of the atmosphere, by which alone the vegetable and animal world can thrive, is alone owing to the rays of the sun, which must thus be regarded as the source of all life upon our planet. Where the mid-day sun stands vertically above the heads of the inhabitants, and its rays strike the earth's surface at a right angle, a luxuriant vegetation is developed, if a second condition of its existence, namely, moisture, be not wanting; but where the solar rays constantly fall too obliquely to produce any marked effect, nature is chained in eternal ice, and all animal and vegetable life ceases.

In order to take a general survey of the distribution of heat on the earth's surface, we must, in the first place, investigate the consequences produced by the diurnal and annual motion of the earth.

In consequence of the annual motion of the earth, the sun continually alters its apparent position in the heavens; the path which it traverses during the year passes through twelve constellations, called the signs of the zodiac.

If we suppose the vault of heaven to be one large concave sphere, the path of the sun will describe a large circle upon it, generally known by the name of the *elliptic*. This line does not coincide with the celestial equator, intersecting it at an angle of $23^0\ 28'$.

Twice in the year, namely, on the 21st of March, and on the

* The want of space prevents this important subject being treated as fully here as it deserves. The reader is therefore referred to the excellent translation of Kaemtz's *Complete Course of Meteorology*, with Notes by *C. V. Walker*, illustrated with 15 plates. London, 1845.

21st of September, the sun passes the celestial equator. From March till September it is on the north, and from September to March on the south hemisphere; on the 21st of June it reaches its most northern, and on the 21st of December its most southern point; being on the first-named day at 23° 28′ north, and the last-named at 23° 28′ south of the celestial equator.

The direction of our earth's axis coincides with the axis of the heavens, the plane of the terrestrial equator, with that of the celestial equator; if, therefore, the sun stand directly upon the celestial equator, its rays strike the earth's surface at every place upon the terrestrial equator perpendicularly at mid-day, whilst they only glance over the two terrestrial poles, striking the parts contiguous to them very obliquely.

If we suppose two circles to be drawn upon the earth's surface parallel with the equator, one 23° 28′ north, and the other equally far south of it, the former will be *the tropic of Cancer,* and the latter *the tropic of Capricorn.* All places lying upon these tropics receive once in the year the sun's rays perpendicularly, this being on the 21st of June for the tropic of Cancer, and the 21st of December for the tropic of Capricorn.

The whole terrestrial zone lying between those two tropics is termed the *hot zone,* because the rays of the sun falling but very little obliquely are able here to produce the most powerful effect.

Heat is tolerably equally distributed throughout the whole year on the equator, because the sun's rays strike the earth rectangularly twice annually, while they do not fall very obliquely at any time intervening between these periods.

The more we approach the tropics, the more marked are the differences of temperature at different periods of the year. In the tropics the solar rays only fall *once* in the year perpendicularly on the earth's surface, and once they make an angle of 47° with the direction of the plumb line, falling, consequently, with very considerable obliquity; the temperature of the hottest and coldest season, separated by a period of half a year, differ very considerably from each other.

On either side of the hot zone, extending from the tropics to the polar zones, (the polar zones are those which have 24 hours exactly for their longest day, and lie exactly 66° 32′ north and south of the equator), are the northern and southern temperate zones; the four seasons of the year are most strongly characterised

in these zones; in general, heat diminishes with the distance from the equator.

Around the poles, extending to the polar tropics, are the northern and southern frigid zones.

In consequence of the rotation of the earth upon its axis, the sun appears to participate in the apparent motion of all the planets; and another result of this diurnal motion, is evidently the alternation between *day* and *night*. It is only during the former period that the solar rays warm the earth's surface, which after sun-set radiates heat towards the heavens without the loss of heat being compensated for; during the night, therefore, the surface of the earth must be cooled.

Under the equator the day and night are equal throughout the year, each day and night lasting 12 hours; as soon, however, as we remove from the equator, the length of the day varies with the season of the year, the variation becoming more striking as we approach nearer to the poles. The following table contains the length of the longest day for different geographical latitudes:

Polar elevation.	Length of the longest day.
0	12 hours.
16^0 44′	13 „
30^0 48′	14 „
49^0 22′	16 „
63^0 23′	20 „
66^0 32′	24 „
67^0 23′	1 month.
73^0 39′	3 „
90^0	6 „

At the equator, therefore, the variation in the day's length cannot exercise any influence upon the course of the heat in the different seasons of the year. As the inequality in the length of the days is not very considerable even under the tropics, the variation in the length of the day between the tropics cannot very much increase or diminish the differences of temperature between the hot and cold seasons of the year; this is the case, to a very considerable degree, in high latitudes.

In summer, when the sun's rays fall less obliquely, the sun remains longer above the horizon in high latitudes; this longer period compensates for what is lost in intensity by the solar rays, and it thus happens that it may be very hot during the summer

even at places which are far removed from the equator, (at St. Petersburgh, for instance, the thermometer sometimes rises in a hot summer to 30°); in the winter, on the other hand, when the more obliquely falling solar rays have only little power of acting, the day is very short, and the night, during which period the earth radiates its heat, extremely long; in consequence of which, the temperature must fall very low at this season. The difference between the temperature of summer and winter will, therefore, generally be greater the further we remove from the equator.

At Bogota, which is 4° 35′ N. of the equator, the difference of temperature between the hottest and coldest month amounts only to 2°; in Mexico (19° 25′ N. lat.) this difference is 8°, at Paris (48° 50′ N. lat.) 27°, and for St. Petersburgh (59° 56′ N. lat.) 32°.

From the above indicated considerations it follows, therefore:

1. That heat must diminish from the equator towards the poles.

2. That in the vicinity of the equator heat is distributed tolerably equally over the whole year, that consequently the character of our seasons ceases there to be recognisable.

3. That the seasons always differ more in proportion as we go further from the equator, and that at the same time the difference between the summer and winter temperature becomes always more considerable.

4. That even in the neighbourhood of the polar circles, the summer may be very hot.

This we find fully confirmed by experience, notwithstanding which, such a consideration can only teach us roughly to know the distribution of heat upon the earth, it being impossible, from the geographical latitude of a place, to draw any conclusion, even remotely certain, as to its climatic relations.

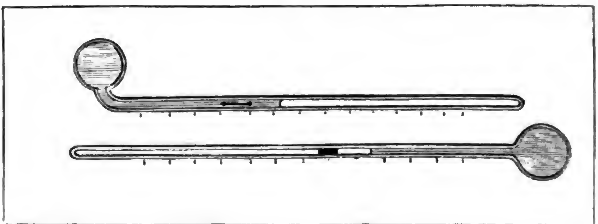
If the whole earth's surface were covered by water, or if it were all formed of solid plane land, possessing everywhere the same character, and having an equal capacity at all places for absorbing and again radiating heat, the temperature of a place would depend only on its geographical latitude, and, consequently, all places having the same latitude would have a like climate. Now, however, the action that may be produced by the solar rays is modified by manifold causes, the climate of one district depending not only upon the direction of the solar rays, but also upon the circumstances under which they act, such as the

conformation of the land and the sea, the direction and height of the mountain range, the direction of the prevailing wind, &c. Hence it follows that places of the same geographical latitude have frequently a very different climate, and we may thus easily see that theoretical considerations do not suffice as data, from whence to draw conclusions regarding climatic relations; the true distribution of heat over the earth's surface, can only be satisfactorily ascertained by means of observations conducted for a protracted term of years. *Humboldt* was the first who entered here with success upon the course of induction, the sole and only path that leads to truth in all physical sciences. On his voyages and travels in both hemispheres, he collected with unwearied zeal facts which, by his excellent mode of combining them, have first laid the foundation of scientific meteorology.

Observation of the thermometer.—In order to be able to observe accurately the temperature of the air at different places, we must place a good thermometer in the open air, upon the north side of a building, and 3 or 4 decimetres removed from the wall, so that it may not receive the sun's rays; we must likewise be careful that there is no white wall in the neighbourhood, from which rays of heat may be reflected towards the thermometer. If the thermometer should be moistened by rain, we must carefully dry the bulb five minutes before we use it, for the suspended drops of water would, by their evaporation, lower the temperature of the mercury in the bulb.

It is often of the greatest importance to meteorology to learn the highest and lowest temperature that may have prevailed during any interval, without it being absolutely necessary to observe the exact moment in which this maximum or minimum occurs. This may be effected by the *thermometrograph*, represented in Fig. 509, which consists of two thermometers, the

FIG. 509.



tubes of which are placed horizontally, and of which one is a mercurial, and the other a spirit thermometer. In the tube of the former lies a steel pin, which is pushed through the column of mercury when the mercury in the bulb expands; when, however, the thermometer is re-cooled the mercurial column recedes, while the steel pin remains in the position to which it was pushed at the highest stand of the thermometer; such a thermometer, consequently, yields the maximum of the temperature that may have prevailed within a certain period.

Within the tube of the spirit thermometer, is a very fine glass rod, somewhat thicker at its extremities, as may be plainly seen in Fig. 509; this glass rod lies within the column of spirits, and on the spirit cooling in the bulb, and the fluid retreating in the tube to the first knob of this rod, the latter will be carried away with the retreating fluid column, when any further sinking of the temperature occurs, owing to the adhesion between the spirit and the glass; if, however, the fluid in the bulb be again warmed, it will, on the rising of the thermometer, pass by the rod without carrying it with it; this index, which must be made of some darkly stained glass, in order to be made more apparent, remains, consequently, lying in the place corresponding to the mininum of the temperature which prevailed within a certain period of time.

When the bulb of the one thermometer lies on the right side, that of the other is on the left, and on inclining the whole apparatus, and striking it gently, the steel rod will fall by its weight on to the column of mercury, and the glass rod to the very end of the column of spirit. If we leave the apparatus thus arranged, the steel rod will be pushed on by every ascent of the temperature, while the glass rod will be drawn back at every depression of the temperature.

This instrument is especially calculated to give the maximum and minimum of the diurnal temperature. On setting it in the proper manner every evening, we may, the following evening, see what has been the highest, and what the lowest temperature during the last 24 hours.

Diurnal variations of temperature.—In order to be able accurately to follow all the variations of heat in the atmosphere during the 24 hours, we must observe a thermometer at very short intervals, as, for instance, from one hour to another. If such observations are to be pursued for any length of time, it is evident that they cannot be conducted by one single individual, but that many must combine for the same purpose; in every case

it is very laborious to institute a series of observations of this kind.

From such series of observations it has been shown that the minimum of temperature occurs shortly before sunrise, and the maximum a few hours after 12 at noon, somewhat later in summer, and somewhat earlier in winter.

This course may be easily explained. Before noon, whilst the sun is constantly rising higher, the earth's surface receives more heat than it radiates; its temperature and that of the atmosphere must, therefore, increase; this continues somewhat beyond noon; but as the sun sinks lower, and its rays become less effective, the heated earth radiates more heat than can be supplied by the solar rays; this cooling naturally continues after sunset, until the morning-dawn announces the return of the sun.

The diurnal variations in the thermometer do not always follow this normal course, which may frequently be disturbed by foreign influences, as, for instance, changes of weather, &c.; in order, therefore, to ascertain with exactitude the law of diurnal variations of heat, we must deduce the mean normal course from a combination of as many numerous observations as can possibly be instituted.

By taking the mean of every 24 hours' observations, we obtain the *mean temperature* of the day.

As it is uncommonly wearisome and laborious to pursue for any length of time these hourly observations of the thermometer, it is of the greatest importance to meteorology to devise methods by which the mean diurnal temperature may be ascertained without making these hourly observations. Twice in the day the thermometer must indicate the mean diurnal temperature; it, therefore, seems the simplest to calculate the hours in which such is the case, and then limit our observations of the thermometer to those periods of the day; such a course may, however, easily lead us into errors, since the thermometer varies most suddenly exactly at this time, and we should thus commit a very considerable mistake in our calculations, if our observations were made either a little too early or too late. A far more correct result is obtained by observing the thermometer at several *similar* hours, for instance, at 4 and 10 A.M., and at 4 and 10 P.M.; this method is, as Brewster has shown, correct to $\frac{1}{10}$th of a degree; we likewise obtain a very useful result by making our observations at 7 A.M. at noon, and at 10 P.M., and then taking the mean of these three periods.

The mean of the highest and lowest degree of the thermometer

during the 24 hours varies so inconsiderably from the actual mean temperature derived from hourly observations, that we may more easily compute the mean diurnal temperature by aid of the thermometrograph described at page 502.

Mean temperature of the months, and of the year.—When we know the mean temperature of all the days of a month, we have only to divide the sum of the mean diurnal temperatures by the number of days, in order to obtain the mean temperature of the month.

On taking the arithmetical mean from the mean temperature found for the 12 months of the year, we obtain *the mean temperature of the year.*

In order to determine with exactness the *mean temperature of a place,* we must take the mean of the mean temperatures obtained from a large series of calculations. In general, the mean annual temperatures do not vary much, so that we obtain the mean temperature of a place with tolerable accuracy, even when we only know it for a few years. For Paris the mean temperatures of the years intervening between 1803 and 1816 were as follows:

10,5^0	10,3^0	9,9^0
11,1	10,6	9,7
9,7	10,5	10,5
11,9	10,5	9,6
10,8	9,9	

The highest of these mean annual temperatures varies only about 2,3^0 from the lowest. On taking the mean of these 14 numbers, we obtain as a mean temperature for Paris 10,2^0, whilst the amount derived from a series of 30 annual mean temperatures is 10,8^0.

In order to find the true mean temperature of a month, we must know the mean temperature of this month for a series of years, and take the mean of these.

The greatest heat generally occurs in our latitudes some time after the summer solstice, and the greatest cold some time after the winter solstice.

July is on an average the *hottest,* and *January* the coldest month. If the period of the highest and lowest temperature is not exactly the same for all places of the same hemisphere, the difference is only occasioned by local influences.

We may, on an average, consider the 26th of July as the hottest, and the 14th of January as the coldest day of the year for the temperate zone of the northern hemisphere.

It has been proved from numerous observations on temperature, that the mean annual temperature generally occurs on the 24th of April, and the 21st of October in the northern temperate zone; the annual course of the heat in these parts is therefore as follows. The temperature rises from the middle of January at first slowly, more rapidly in April and May, and again more slowly until the middle of July, from which period it diminishes, but slowly in August, more rapidly in September and October, finally reaching its minimum again in the middle of January. This admits of an easy explanation. When the sun, after the winter solstice, again ascends, this ascent goes on so slowly, and the days increase so little, that as yet no more powerful effect from the sun's rays is possible. On this account, the minimum of the yearly temperature occurs after the winter solstice; a rise of temperature first takes place when the sun has returned somewhat farther north. About the time of the equinoxes, the sun's progress in the heavens towards the north is quickest: the increase of temperature for this reason is at this time the most perceptible.

When the sun has attained its highest position, the earth has not yet become so warmed that the heat which the ground loses by radiation is equal to the quantity of heat which it receives from the sun's rays; the balance would only be restored after the sun had remained a longer time at its northern solstice. But now the sun goes back after its summer solstice, very slowly at first. The effect of the sun's rays is for some time quite as powerful as at the moment of the solstice; the temperature, therefore, will still rise after the longest day, and indeed even to the middle of July, and then again fall. These considerations lead to the division of the year into four seasons.

The astronomical division, when the seasons are limited by the equinoxes and solstices, is the most suitable to meteorology. It would be better were we to divide the year in such a manner, that the hottest month (July) should fall in the middle of summer, and the coldest month (January) in the middle of winter. According to this, *winter* would include the months of December, January, and February; *spring*, March April, and May; *summer*, June, July, and August; and *autumn*, September, October, and November. According to this signification we must understand the seasons given in the following table, which contains the mean annual temperature, mean temperature of individual years, and the hottest and coldest months for a large number of places scattered over different parts of the earth's surface.

Places.	Latitude.	Longitude E. and W. of Paris.	Elevation above the level of the sea in metres.	Mean temperature of: The year.	Winter.	Spring.	Summer.	Autumn.	The coldest month.	The hottest month.	Number of years during which observations were made.
Melville Island	74° 47′ N.	113° 8′ W.	—	— 18,7	— 33,5	— 19,5	2,8	— 18,0	— 35,8 Febr.	5,8 July.	1
Ustjansk	70 55 —	136 4 E.	—	— 16,6	— 38,4	— 14,7	9,2	— 23,9	— 40,3 Jan.	13,7 —	1—3
Jakuzk	62 1 —	126 47 —	117	— 9,7	— 38,9	— 8,3	17,2	— 6,6	— 40,5 Febr.	20,3 —	....
Rain (Labrador)	57 10 —	64 10 W.	—	— 3,6	— 18,5	— 5,8	7,6	— 2,2	— 20,9 —	9,3 Aug.	3
St. Bernard	45 50 —	4 45 E.	4843	— 1,0	— 7,8	— 2,0	6,1	— 0,4	— 8,7 Jan.	6,8 July.	21
Irkutsk	52 16 —	101 58 —	409	— 0,2	— 17,6	4,5	15,9	— 2,2	— 19,5 —	17,5 —	10
North-Cape	71 10 —	23 30 —	—	0,1	— 4,6	— 1,3	6,4	— 0,1	— 5,5 —	8,1 —	1
Kasan	55 48 —	46 47 —	58	2,2	— 14,3	2,6	17,0	2,8	— 16,5 —	18,4 —	12
Petersburg	59 56 —	27 59 —	—	3,5	— 8,4	1,7	15,7	4,7	— 10,3 —	16,9 —	25
Reikiavig (Iceland)	64 8 —	24 16 W.	—	4,0	— 1,6	2,4	12,0	3,3	— 2,1 Febr.	13,5 —	14
Christiana	59 54 —	8 25 E.	—	5,4	— 3,8	4,0	15,3	5,8	— 4,8 Jan.	16,5 —	10
Königsberg	54 43 —	18 10 —	—	6,2	— 3,3	5,3	15,9	6,7	— 4,2 —	17,0 —	24
Bern	46 57 —	5 6 —	585	7,8	— 0,9	7,7	15,8	8,5	— 2,8 —	16,6 Aug.	20
Augsburg	48 22 —	6 34 —	493	7,9	— 0,7	8,3	16,6	8,2	— 3,8 —	17,5 July.	22
Edinburgh	55 57 —	5 32 W.	88	8,6	3,6	7,6	14,4	8,9	— 2,9 —	15,0 —	17
Hamburgh	53 33 —	7 38 E.	—	8,6	0.3	8,0	17,0	8,8	— 1,8 —	17,5 —	19
Berlin	52 31 —	11 3 —	39	8,6	— 0,8	8,0	17,3	8,8	— 2,4 —	18,0 —	25
				8,6	— 0,7	8,4	17,6	9,1	— 3,1 —	18,3 —	22
Tubingen	48 31 —	6 43 —	331	8,6	— 0,2	8,6	17,1	8,9	— 2,2 —	17,8 —	13
Munich	48 9 —	9 14 —	526	8,9	— 0.4	9,0	17,4	9,1	— 1,5 —	18,0 —	32
Geneva	46 12 —	3 49 —	396	9,7	1,2	9,5	17,9	10,2	— 0,4 —	18,6 —	40
Frankfort-on the-Maine	50 7 —	6 21 —	117	9,8	1,2	9,9	18,3	10,0	— 0,4 —	18,9 —	30
Strasburg	48 35 —	5 25 —	146	9,8	1,1	10,0	18,1	10,0	— 0,4 —	18,8 —	32
Vienna	48 13 —	14 3 —	156	10,1	0,2	10,5	20,3	10,5	— 1,6 —	20,7 —	24—14
London	51 31 —	2 26 W.	92	10,4	4,2	9,5	17,1	10,7	3,0 —	17,8 —	40
Paris	48 50 —	0 0 —	64	10,8	3,3	10,3	18,1	11,2	1,8 —	18,9 —	33
Baltimore	39 17 —	78 58 —	....	11,6	0,4	10,4	23,1	12,9	0,6 —	24,0 —	8
Padua	45 24 —	9 32 E.	49	12,5	2,8	12,1	21,9	13,0	1,8 —	22.9 —	37
Bordeaux	44 50 —	2 55 W.	—	13,9	6,1	13,4	21,7	14,4	5,0 —	22,9 —	10
Madrid	40 25 —	6 2 —	663	14,2	5,6	14,2	23,4	13,7	....	......	2—3
Santa-Fe-de-Bogota	4 36 —	76 34 —	2631	15,0	15,1	15,3	15,3	14,5	14,0 July.	16,1 Aug.	1—2
Rome	41 54 —	10 8 E.	53	15,4	8,1	14,1	22,9	16,5	7,2 Jan.	23,9 July.	30
Quito	0 14 S.	81 5 W.	2914	15,6	15,4	15,7	15,6	17,5	14,8 July.	16,3 March.	2—3
Lisbon	38 42 N.	11 29 —	72	16,4	11,3	15,5	21,7	17,0	11,2 Jan.	22,3 July.	5
Mexico	19 26 —	101 26 —	2271	16,6	13,0	18,1	19,1	16,2	12,3 —	19,7 June.	2
Palermo	38 7 —	11 1 E.	55	17,2	11,4	15,0	23,5	19,0	10.7 Febr.	24,6 Aug.	39
Algiers	36 47 —	0 43 W.	—	17,8	12,4	17,2	23,6	21,4	(14,5) March.	24,7 —	4
Cape of Good Hope	33 55 S.	16 8 E.	—	19,1	14,8	18,6	23,4	19,4	14,3 Aug.	24,4 Jan.	7—11
Las-Palmas (Canary Islands)	28 0 N.	17 51 W.	—	21,8	18,0	19,4	23,8	26,2	17,8 Jan.	29,2 Oct.	12
Calcutta	22 35 —	86 0 E.	—	28,5	19,9	28,1	28,5	26,1	18,4 —	29,9 May.	17—8
Jamaica	17 50 —	79 2 W.	....	26,1	24,6	25,7	27,4	26,6	24,4 —	27,7 July.	5
Batavia	6 9 S.	104 33 E.	—	26,8	26,2	26,8	27,2	27,1	25,9 June.	27,8 Jan.	1
Madras	13 5 —	77 57 —	—	27,8	24,8	28,6	30,2	27,5	24,1 Jan.	31,3 June.	25
Massowa (Abyssinia)	15 36 —	37 9 —	—	(31,0)	26,7	29,5	....	32,0	25,5 —	(33,8) Sept.	1

The numbers of this table are only mean numbers, from which the true temperature inclines sometimes towards one side, sometimes towards the other, and thus, too, the mean temperatures of the hottest and coldest months by no means indicate the lim ts between which the thermometer may fluctuate at one and the same spot. It thus happens, that even in districts enjoying a warm climate and a mild winter, an extraordinary degree of cold is often felt; thus, for instance, in the year 1507 the harbour of Marseilles was frozen over its whole extent, for which a cold of at least, — 18° was requisite; in the year 1658, Charles X., with his whole army and their heavy artillery, crossed the little Belt. In 1709 the Gulf of Venice, and the harbours of Marseilles, Genoa, and Cette were frozen over; and in 1789 the thermometer fell at Marseilles to — 27°. The following table gives the highest and lowest degrees of temperature observed at different places.

	Minimum.	Maximum.	Difference.
Surinam	21,3°	32,3°	11,0°
Pondicherry . . .	21,6	44,7	23,1
Esna (Egypt) . . .		47,4	
Cairo	9,1	40,2	31,1
Rome . . .	— 5,9	38,0	43,9
Baris	— 23,1	38,4	61,5
Prague . . .	— 27,5	35,4	62,9
Moscow . . .	— 38,8	32,0	78,8
Fort Reliance (North America)	— 56,7		

Considerable deviations from the normal annual course of heat do not occur locally, but are scattered over wide districts; thus, for instance, the winter of 1821 and 1822 was very mild in Europe, but in the December of the latter year a severe cold prevailed over the whole of Western Europe, a similar very considerable deviation never has, however, been spread over an entire hemisphere. The northern hemisphere is generally divided in a northern to a southern direction into two halves, upon which opposite deviations from the normal temperature may be observed; these deviations are greatest in the middle of the two halves, while a more average temperature is perceived where they approach each other.

Thus, in February, 1828, it was very cold in Kasan and Irkutzk, unusually mild in North America, whilst Europe remained unaffected between these two opposite deviations. In December, 1829, this maximum of cold inclined towards Berlin,

while it also continued to be very marked at Kasan; in North America, however, the weather was unusually mild, but in December, 1831, the excessive cold was limited to America. Generally speaking, these deviations from the average range of heat are observed to be similar in Europe and Asia, and opposite in America.

Frequently, although not so remarkable, the boundary line of opposite deviations runs from east to west.

A deviation from the mean temperature often continues for a long time in the same direction. Thus, from June, 1815, to the December of 1816, there prevailed in Europe an unusually low degree of temperature, which occasioned the failures in the crops in 1816; 1822 was a remarkable year for the vines, the unusual heat continuing then from November, 1821, to November, 1822.

From this it follows, that the opinion so prevalent of a cold winter succeeding a hot summer, and a warm winter a cold summer, is altogether erroneous, since the contrary often occurs, as may be seen from the examples above given; thus, too, the hot summer of 1834 succeeded a very mild winter.

These deviations from the mean range of heat are more marked in winter than in summer.

From all this it appears highly probable that the same quantity of heat is always distributed over the earth's surface, although unequally. A cold winter is the consequence of a long prevalence of north-east winds, and a cold summer is induced by the continuance of south-west winds; these alternating exclusively prevalent currents of air being, as *Dove* has shown, the controlling agents in the relations of weather. If a hot summer is to succeed a cold winter, the north-east wind must prevail throughout the whole year; while, on the other hand, the wind must blow chiefly from the south-west for the same space of time to bring a cold summer after a mild winter.

Isothermal lines.—A table of the kind given at page 507, contains many of the elements, from which we may calculate the distribution of heat over the earth's surface. At all events, we may see from such a table that all places lying under the same degree of latitude have not the same mean temperature. Thus, for instance, the mean annual heat at the North Cape is $-0{,}1^0$; whilst Nain, on the coast of Labrador, has a mean annual temperature of $-3{,}6^0$, although Labrador is 14^0 south of the North Cape. *Humboldt* was the first to give us a clear view of the

distribution of heat over the earth, making use, for this purpose, of his *isothermal lines*, by which he connected together all such places in the same hemisphere having equal mean annual temperatures.

If we suppose, for instance, a traveller starting from Paris to make a journey round the earth in such a manner as to visit all places of the northern hemispheres which have the same mean annual heat as Paris, that is, 10,8°, the course he will thus pursue will *be a line of equal mean annual heat*, consequently an *isothermal line*; this line, instead of corresponding with the degree of latitude of Paris, will be irregular and curved, passing through places having a very different latitude from Paris.

Fig. 510 represents the earth's surface in Mercator's proportions, with the *isothermal* lines at every 5 degrees. At the terrestrial equator, the mean temperature of the sea-coast is 27,5°, although somewhat less upon the western coast of America and Africa; in the interior of these two continents, especially in that of Africa, the mean temperature is higher than on the sea-shore, the mean temperature of the equator in the latter continent is above 29°.

An examination of the chart in Fig. 510 will spare us a further description of the course of the isothermal lines. We observe how considerable their curves become in the northern hemisphere the further we remove from the equator; the isothermal line of 0°, for instance, ascends from the southern end of the coast of Labrador across Iceland towards the North Cape, in order to decline again considerably in the interior of Asia.

Where the isothermal lines incline the farthest towards the south, they describe a concave; and where they ascend the highest towards the north, a convex vertex. The southern turning points of the isothermal lines lie in the east of North America and in the interior of Asia, while the northern turning points lie on the western coasts of Europe and America.

The relations of temperature of the southern hemisphere are not nearly so perfectly known to us as those of the northern hemisphere; we may, however, consider it as established, that the southern is colder than the northern hemisphere, although the difference may perhaps be less considerable than we are generally disposed to assume it. The circumstance that has probably contributed to the opinion that the southern is so much colder than the northern hemisphere, is, that the relations of temperature of the southern part of America have been compared with those of

FIG. 510.

like northern latitudes in Europe, where the isothermal lines ascend so very considerably to the north; the matter is very different when we compare districts of South America with those lying equally far from the equator on the east side of North America.

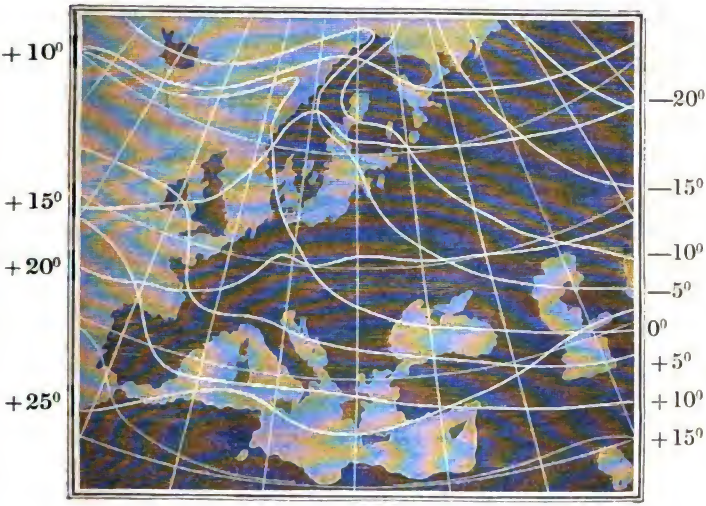
That the southern hemisphere is somewhat colder than the northern, arises probably from the fact, that in the former water, and in the latter land predominates. The continent is much more heated by the absorption of the sun's rays than the sea, which reflects a great portion of them.

Isothermal and isochimenal lines.—We have thus stated that all places lying on the same parallel circle have not the same climate; here, however, the question arises, whether all places on the same isothermal lines, consequently such as have the same mean annual heat, have likewise otherwise equal climatic relations. We need only look at the table, page 507, in order to convince ourselves that such is not the case. Thus, for instance, Edinburgh and Tubingen have the same mean annual temperature of $8{,}6^0$; at the former place, however, the mean temperature of winter is $3{,}6^0$, at the latter $0{,}2^0$: Tubingen consequently has a far colder winter than Edinburgh. But then, again, the mean summer temperature of Tubingen is $17{,}1^0$, while it is only $14{,}4^0$ for Edinburgh. With a like mean annual temperature, Edinburgh has, therefore, a milder winter and a colder summer than Tubingen.

In order to know the relations of heat of a country, it is not sufficient to be acquainted with its mean annual temperature, we must also know how heat is distributed during the different seasons of the year. This distribution may be shown upon an isothermal chart, by setting down, according to *Humboldt's* idea, the mean summer and winter temperature against the different places upon one and the same isothermal line, which could not be done on our isothermal chart, owing to its small size; we shall thus see, that in the immediate vicinity of the convex summit of the isothermal lines, the differences between the mean summer and winter temperature are the least; the same reasons, consequently, which cause the isothermal lines upon the western coast of Europe and America to rise so far to the northward, make the difference between the summer and winter temperature less considerable. A very good idea of the distribution of heat in winter and summer may be obtained by means of a chart, in which all places having the same mean winter temperature are connected together

by curved lines, as are also all the places that have the same mean summer temperature. The lines of like mean winter temperature are termed *isochimenal*, and those of like mean summer temperature, *isothermal*. Fig. 511 represents a small chart of Europe with the isothermal and isochimenal lines drawn at every 5 degrees.

FIG. 511.



The curves, whose corresponding temperatures are on the right side of the chart, are the *isochimenal*, and the other the *isothermal lines*. We may easily see from this chart, that the western coasts of the southern part of Norway, Denmark, a portion of Bohemia and Hungary, Transylvania, Bessarabia, and the southern extremity of the peninsula of the Crimea, have the same mean winter temperature of 0°. Bohemia, however, has the same summer heat as the districts lying at the mouth of the Garonne, and in the Crimea the summer is far hotter. Dublin has the same mean winter temperature, viz. 5°, as Nantes, Upper Italy, and Constantinople, with the same summer heat as Drontheim and Finland.

The isothermal line of 20° passes from the mouth of the Garonne, nearly over Strasburg and Wurzburg to Bohemia, the Ukraine, the country of the Don Cossacks, somewhat to the north of the Caspian Sea; how different, however, is the mean winter

temperature at different places upon this line! On the western coasts of France it is 5°, in Bohemia 0°, in the Ukraine — 5°, and somewhat to the north of the Caspian Sea even — 10°.

The climate on land and at sea.—The consideration of the last map, and the table at page 507, lead us to the important difference between the climate at sea and on the land, or as we may also express it, between the continental and littoral climate. The differences between the summer and winter temperature increase with the distance from the sea; on the sea-side the summers are cool and the winters mild, whilst in the interior we have hot summers and cold winters. These differences appear very marked, on comparing the relations of temperature of the western shores of Europe with those of northern Asia. In order to be able easily to mark the relation of the mean annual temperature to the distribution of heat, we have sat down from examples derived from the table, page 507, the mean annual temperature first, the mean summer temperature above, and the mean winter temperature below a horizontal line:

Littoral climate.			Continental climate.		
North Cape	0,1	$\frac{6,4}{-4,6}$	Jakuzk	— 9,7	$\frac{17,2}{-38,9}$
Reikiavig	4,0	$\frac{12,0}{-1,6}$	Irkuzk	— 0,2	$\frac{15,9}{-17,6}$
			Moscow	— 3,6	$\frac{16,8}{-10,3}$

The influence that such climatic differences must exercise upon vegetation is evident. Thus, in many parts of Siberia, at Jakuzk, for instance, where the mean annual temperature is — 9,70, while the mean winter temperature is — 38,9°, wheat and rye are raised upon a soil which remains constantly frozen at the depth of 3 feet; while in Iceland, where the mean temperature of the year is very much higher, and the winter's cold but inconsiderable, it is impossible to raise any of the cereals, as the low summer temperature does not suffer them to ripen.

In the north-east of Ireland, where there is scarcely any ice or frost in the winter, at the same latitude as Königsberg, the myrtle thrives as well as in Portugal; on the coast of Devonshire, the *Camellia Japonica* and the *Fuchsia Coccinea* live through the winter in the open air; the winter is not colder in Plymouth than in Florence and Montpellier; the vine will not thrive in

England, however, for, although it can endure a tolerably strong degree of cold, it requires a hot summer to make the fruit ripen and yield a drinkable wine.

These differences are owing to the more easy absorption and radiation of heat, which becomes heated and again cooled more rapidly than the sea, which by the continent is everywhere of an uniform nature, and from its transparency and the considerable amount of specific heat of water, is neither so rapidly heated, nor so speedily deprived of the heat it has once acquired. The temperature of the surface of the sea is on that account far more uniform, the diurnal as well as the annual alternations are incomparably less than in the middle of large continents, whence arises the above-mentioned difference between the climate on the land and at sea; it is likewise augmented by the sky, which is mostly overcast on the shores of countries lying towards the north, and tempers the heating influence of the solar rays in summer, and checks the excessive cooling of the earth in winter by radiation of heat.

Causes of the curvature of the Isothermal lines.—The most important causes that contribute to the curvature of the isothermal lines so much to the north on the western shores of Europe and America, are essentially as follows:

In the northern temperate zone, south-west and north-east winds prevail. The former come from the equatorial districts, and partially bear the heat of the tropics towards colder regions; this warming influence of the south-west winds is, however, most marked in those districts which are the most exposed to south-western currents of air, and thus we see why it is that the western shores of great continents become warmer than the eastern coasts, and that the isothermal lines in Europe, which is actually only a peninsular prolongation of the Asiatic continent, and on the western shores of North America, ascend further to the north than in the interior of Asia, and on the eastern shores of North America.

A second cause, to which Europe owes its relatively warm climate, is this, that in the equatorial region it is bounded towards the south, not by a sea, but by an extensive continent, Africa, whose vast extent of desert and sand render it extremely hot when exposed to the vertical solar rays. A warm current of air rises continually from the glowing hot sandy wastes, to descend again in Europe.

Finally, the current known by the name of the *Gulf Stream* contributes considerably to make the European climate milder. The origin of this current is to be sought for in the Gulf of Mexico, where the water is at a temperature of 31°. Issuing from the Gulf between Cuba and Florida, the stream at first skirts the American shores, and then, as it comes into higher latitudes, turns with decreasing temperature eastward towards Europe. Although the Gulf Stream does not actually reach the shores of Europe, it nevertheless distributes its heated waters, under the influence of the prevailing south-west winds, to the European waters, as is proved by our finding, on the western shores of Ireland and on the coast of Norway, the fruits of trees that grow in the hot zone of America; the west and south winds remain, therefore, long in contact with a sea water, whose temperature between 45 and 50 degrees of latitude does not even in January sink below from 10,7 to 9°. Northern Europe is thus separated by the influence of the Gulf Stream from the circle of polar ice by means of a sea free from ice; even at the coldest season of the year the limits of polar ice do not reach the European shores.

Whilst all circumstances thus combine to raise the temperature in Europe, many causes contribute in Northern Asia to lower the isothermal lines very considerably. In the south of Asia there are no extensive districts of land between the tropics, but merely a few peninsulas comprised within this zone; the sea, however, does not become so much heated as the African deserts, partly because the water absorbs rays of heat to an incomparably smaller extent, and partly also because a great quantity of heat goes off in the latent state, owing to the constant evaporation of water from the surface of the sea. The warm currents of air, which, rising from the basin of the Indian Ocean, would convey the heat of the tropics to the interior and north of Asia, are impeded in their course by the huge mountain ranges in the south of Asia, whilst the land, which gradually flattens towards the north, is left exposed to the north and north-east winds. While Europe does not stretch far northward, Asia penetrates a considerable way into the Arctic Sea, which, deprived of all those heating influences by which the temperature of the European seas is raised, is almost always covered with ice. In every direction the northern shores of Asia penetrate the wintry limits of the polar ice, the summer boundary of which is only removed

for a short time and at a few places from the coasts; that this circumstance, however, must considerably lower the temperature, will be easily understood when we consider how much heat becomes latent by the fusion of such masses of ice.

The considerable depression of the isothermal lines in the interior and upon the eastern shores of North America, depends in part upon the south-west winds, which not being sea, but land-winds, are therefore unable any longer to diffuse the milder influence that they exert upon the western shores. Whilst the European shores are washed by warmer waters, cold sea-currents come from the north and south towards the eastern shores of North America. Such a current, coming from Spitzbergen, passes between Iceland and Greenland, and then combines with the currents that come from Hudson's Bay and Baffin's Bay, passes down the coast of Labrador, past Newfoundland, and empties itself finally in the Gulf Stream at 44^0 N. lat. This arctic current bears the cold of the polar regions, partly by the low temperature of the water, but chiefly by floating icebergs, into the southern districts, and thus becomes a main cause of the considerable depression of the isothermal lines on the eastern coasts of America.

Temperature of the ground.—We have hitherto only spoken of the temperature of the air, and not of that of the upper layers of the ground, which vary considerably from the temperature of the air, according to the nature of the surface. Where the soil is barren, deprived of vegetable growths, stony or sandy, it becomes far hotter by the absorption of rays of heat than one that is covered with plants; for instance, a piece of meadow-land becomes much cooler by nocturnal radiation than the air, whose temperature is made more uniform by the effect of continued currents. In the deserts of Africa, the heat of the sand often amounts to from 50 to 60^0. A soil covered with vegetable growths remains cooler, owing to the solar rays not striking it directly; the plants themselves combine, to a certain degree, a large amount of heat, whilst a quantity of water is evaporated by vegetation; but they cool so considerably in their great capacity of emission of heat by radiation, as we shall see when we come to speak of the formation of dew, that the temperature of the grass often falls from 6 to 9^0 below that of the air. In the interior of woods and forests the air is constantly cool, owing to the thick leafy covering acting in the same cooling manner as the covering

of grass, and because the cooled air is precipitated upon the tops of the trees.

The heat on the uppermost surface of the ground can only penetrate to the interior by degrees, owing to its imperfect capacity for conducting heat; the deeper layers of the soil lose their heat less rapidly than the upper ones, and thus at some little depth the variations of temperature are less marked than on the surface itself. In Germany these variations of temperature disappear at a depth of 6 decimetres, and at a greater depth the annual variations even vanish; so that a temperature prevails here differing but little from the mean temperature of the place.

Although all the heat upon the earth's surface comes from the sun alone, the earth has also its own peculiar heat, as may be proved by the increase of temperature observed at great depths. If the heat augment towards the centre of the earth in the same proportion as our observations indicate, at the depth of 3200 metres, there would be a temperature equal to that of boiling water, while at the centre of the earth all bodies would be in a state of fusion. That upon the surface of our planet we perceive nothing of this intense heat of its interior may be explained by the bad capacity for conducting heat possessed by the cooled earth's crust which surrounds this glowing nucleus.

Springs that yield the most copious supply of water vary but little in their temperature at the different seasons; in our hemisphere they attain their highest temperature in September, and their lowest in March; the difference between the two amounting generally to only 1 or 2^0.

Springs which arise from a great depth have a far higher temperature, as is the case with salt and other mineral springs. The water of many of these salt springs has almost the temperature of the boiling point.

Decrease of temperature in the upper regions of the air.—The heating of the air arises from two causes: in the first place it absorbs a part of the rays of heat coming from the sun; but as the air absorbs rays of heat to a much more inconsiderable degree than the earth's surface, the air is likewise much less heated by the absorption of rays of heat than the ground; thus the atmosphere receives the greatest portion of its heat from below.

If the air were not an elastic fluid, the density of the atmosphere would remain the same for all elevations; the strata of air warmed upon the surface would ascend to the limits of the atmosphere, and

the uppermost strata of the air surrounding our earth would likewise be the warmest. But as the warm strata of air expand in their ascent, heat is absorbed by this expansion, and their temperature lowered: from which it follows that the higher strata are the coldest.

We may easily convince ourselves that such a depression of temperature actually occurs in the higher regions of the air, when we ascend into these regions by means of a balloon, or to the summit of some high mountain.

In the Alps an elevation of 180 metres corresponds, on an average, to a depression of temperature of 1°.

As a consequence of the decrease of temperature with an increase of altitude, the summits of high mountains are always covered with snow.

The limits of perpetual snow naturally lie higher in proportion as we approach the torrid zone.

The height of the snow-line is as follows:

The coast of Norway .	720	metres
Iceland	936	,,
The Alps . . .	2708	,,
Mount Etna . . .	2905	,,
The Himalayas . .	4500	,,
Mexico	4500	,,
Quito	4800	,,

CHAPTER II.

ON THE PRESSURE OF THE ATMOSPHERE AND WINDS.

We have already seen that the pressure of the air is measured by the barometer. We, however, observe constant variations in this instrument, indicative of an alternate decrease and increase in the pressure of the atmosphere.

These variations of the thermometer are either periodical or accidental.

Periodical variations are very marked in their character in the tropics; for instance, the thermometer falls from 10 A.M. to 4 P.M., then rises until 11 P.M.; falls again till 4 A.M., and again rises

until 10 A.M. The barometer thus indicates two daily maxima, at 10 A.M. and at 11 P.M., and two minima, at 4 A.M. and at 4 P.M.

The amount of these diurnal variations is about 2^{mm}.

An annual period of the fluctuations of the barometer is also very strongly marked within the tropics. Thus, north of the equator the barometer falls from January till July, and then rises again from July to January. In July the barometer stands, on an average, from 2 to 4 millimetres lower than in January.

In higher latitudes, the accidental fluctuations of the barometer are so considerable as to make one lose sight of the trifling periodic variations presented in these regions. In order to decide whether there is not also a periodical rise and fall in the accidental oscillations of the barometer, it is necessary to compare the mean numbers of a large series of barometic observations made at regularly settled hours of the day. If we observe the barometer for the term of a month at several fixed hours of the day, and take the mean of all the observations, it will suffice to prove the existence of a diurnal period of the fluctuations of the barometer even for our own region.

Observations of this kind have proved that these periodical oscillations occur even in our latitude, the barometer standing at 9 A.M., on an average, 0,7 millimetres higher than at 2 P.M.; the mean height of the barometer is also somewhat less in summer than in winter.

Causes of the oscillations in the barometer.—The cause of all these oscillations is to be sought for in the unequal and constantly varying distribution of heat over the earth's surface. As the distribution of heat constantly varies, the equilibrium is likewise disturbed at every moment, and currents of air arise, which strive to restore the balance; the air is thus in constant motion, sometimes more heated and then lighter, and at other times more cooled, and consequently denser. As it contains sometimes more, sometimes less vapour, the pressure of the columns of air will also be exposed to continual changes, indicated by the barometer.

That actual changes of temperature are really the causes of the oscillations of the barometer, is proved by their being most inconsiderable in the tropics, where the temperature varies so little; in higher latitudes, on the contrary, where the variations of temperature are always more considerable, the amplitude of the accidental oscillations of the barometer is likewise very great:

even in summer, when the temperature is generally less changeable, the oscillations of the barometer are less than in winter.

Although we may generally show that the unequal and constantly varying temperature of the air must be followed by constant changes in the amount of the atmospheric pressure, we are, however, still far from being able satisfactorily to explain these phenomena.

If the air is much heated at any spot, it expands, the column of air rises above the mass of air, and rests upon the colder parts surrounding it; the ascended air consequently flows off laterally from above, the pressure of the air must decrease at the warmer places, and the barometer sinks; in the colder parts, however, the barometer ascends, because the laterally diffused air in the upper regions of the heated places is distributed over the atmosphere of the cooler parts.

We hence see why in our districts the barometer stands on an average lowest with a south-west and highest with a north-east wind: the former winds bring us warm, and the latter cold air. Whenever there is a warm current of air, the atmosphere must have a greater height than where the cold wind prevails, if the pressure of the whole column of air is to be equal at both places; and if such were actually the case, the air of the warm current would flow off from above, consequently the barometer would fall when exposed to the warm, and rise when exposed to the cold.

In Europe south-west winds generally are the ones which bring rain, because, coming from warmer seas, they are saturated with vapour, which, gradually condensing, falls as rain when the wind reaches colder districts. In this condensation of vapour we have another reason why the barometer falls with the south-west winds. As long, for instance, as the vapour of water as a gas forms a constituent of the atmosphere, it contributes to the atmospheric pressure, and thus a portion of the column of mercury in the barometer is sustained by the vapour, and the barometer falls when the vapour is separated by condensation from the atmosphere.

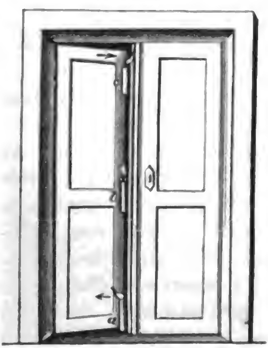
As the south-west winds, which occasion a sinking of the barometer in our latitudes, bring a damp air and rainy weather, whilst the north-east winds, which dry the air and clear the sky, cause the barometer to rise, we may say that in general a high state of the barometer indicates fine weather, whilst its depressed condition forebodes the contrary. This is, however, only, as we have before remarked, an average rule, for the sky is often cloudy with a

north-east wind, and clear with one coming from the south-west; the statement is in so far true as that the barometer stands high or low according to which of these two winds prevails, the remark in the latter case being nearly true on an average. We are unable to account for such anomalies, from our insufficient knowledge of the manifold elements which affect the condition of equilibrium of the atmosphere.

That a high state of the barometer generally indicates clear weather, and a fall of the mercury in the barometer tube the contrary, is only true for those places where the warm winds are those which bring the rain. At the mouth of the river La Plata, for instance, the cold south-east winds coming from the sea, and which cause the barometer to rise, are winds which bring rain, while the warm north-west winds, that make the barometer fall, are dry land-winds, and bring clear weather. To the cause that rain is here conveyed by cold winds is to be ascribed the small quantity of rain in these regions; whilst at the same latitude on the western coast of South America much rain falls, although here, too, the warm north-west wind comes from the sea.

Origin of the winds.—If in winter we partially open the door of a heated apartment communicating with a cold space, and hold a burning taper to the upper part of the crevice (as seen in Fig. 512) the outward direction of the flame will indicate the presence of a current of air passing from the heated apartment into the cooler atmosphere. As we move the taper downward, the flame will constantly become more and more upright; until at about the middle of the height it will remain perfectly still, being no longer affected by currents of air. On moving it downward, however, the flame will be driven inward. We thus see that the heated air flows out at the top of the room, whilst the cold air enters near the floor.

FIG. 512.



As here the unequal warming of the two spaces gives rise to currents of air on a small scale, so does the unequal and ever-changing warming of the earth's surface give rise to those currents of air which we call *winds*. Here, too, we may see the air ascend

in the more heated regions, and flow off towards the colder parts, whilst below, the air flows from the colder to the warmer regions.

We have a simple illustration of this in those land and sea-winds, which we so frequently observe on the sea-shore, especially of islands. A few hours after sunrise a land-wind sets in from the sea, owing to the land being more strongly heated than the sea by the sun's rays; the air rises over the land, and flows towards the sea, while from below, the air is borne from the water towards the shore. This *sea-wind* is at first but light, and only perceptible on the coast; by degrees, however, it increases, and then it may be felt out at sea at a considerable distance from land; between 2 and 3 P.M., it is strongest, afterwards dying away, until at sunset a calm sets in. The land and sea are now cooled by the radiation of heat towards the sky, the former, however, more rapidly than the latter, and the air then flows towards the sea from the lower regions of the land, whilst an oppositely directed current is perceptible in the upper regions of the air.

A rapid condensation of atmospheric vapour is also to be reckoned amongst the causes, which give rise to violent storms. When we consider what an enormous mass of water falls to the ground during a sharp shower of rain in the course of a few minutes, and what an enormous volume this water must have comprised when suspended in the air in the form of vapour, it appears evident that a considerable rarefaction of the air must be occasioned by this sudden condensation of vapour, and that it must rush with violence into the rarefied space, the more so, as owing to the condensation of the vapour, the temperature of the air is raised by the liberated heat, and a strong rising current thus engendered.

We often observe the clouds pass in a direction different from the one indicated by the weather-cock, and that the higher clouds move in an opposite direction to those below them, whence it is evident that at different elevations currents of air move in contrary directions.

Trade-winds and monsoons.—When *Columbus*, on his voyage of discovery towards America, saw that his ship was driven on by a continual east wind, his companions became filled with terror, as they feared they should never be able to return to Europe. This wind of the tropics, which constantly blows from the east

to the west, and so greatly excited the wonder of the firs navigators of the 15th century, is the *trade-wind*. Seamen avail themselves of this wind to sail from Europe to America, by steering southward from Madeira to the vicinity of the tropic, where they are then carried westward by the trade-wind. This course is so certain, and attended with so little labour, that the Spanish sailors gave the name of Ladies' Gulf (*el Golfo de las Damas*) to this portion of the Atlantic ocean. This wind also blows in the South Sea, and the Spanish navigators let their ships be propelled by it in a straight line from Acapulco to Manilla.

In the Atlantic Ocean the trade-winds extend from 28^0 to 30^0 lat.; but in the great ocean (the Pacific) only to 25^0 N. lat. In the northern half of the torrid zone, the *trade-wind* blows in a *north-east* direction, and becomes more decidedly east as it approaches the equator. The limits of the trade-wind are less well defined in the southern hemisphere, where it has a south-east direction, and inclines more towards due east the more it approaches the equator.

These winds blow round the whole globe, but as a general rule they do not become perceptible within fifty German miles from the land.

Where the north-east trade-wind meets the south-east trade-wind of the southern hemisphere, the two merge into a purely eastern wind; which, however, is not perceptible, because the horizontal motion of the air (which has been heated by the intensity of the sun's rays, and thus made to ascend) is neutralized by this vertical motion. There would be almost a perfect calm in these regions if the violent storms accompanying the torrents of rain, which occur almost daily with thunder and lightning, were not to disturb the calm of the atmosphere, and prevent the blowing of soft regular winds.

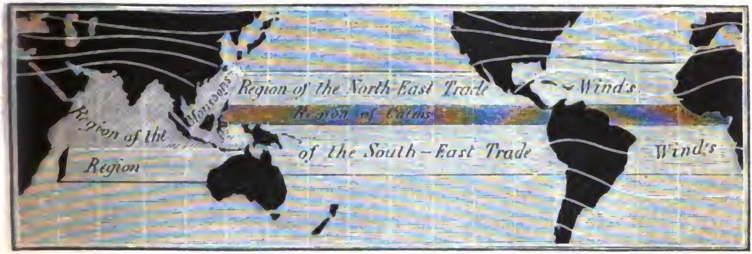
This zone, which separates the trade-winds of both hemispheres, is the *region of calms*.

The little map seen in Fig. 513, serves to indicate the regions in which the trade-winds prevail. The middle of the region of calms, extending about 6^0 in width, does not coincide with the equator, as we might be led to expect, but lies to the north of it. During our summer months, the zone of these calms is broader, and its northern boundary is further removed from the equator, whilst its southern line is but little changed.

The cause why the region of calms lies in the northern

hemisphere, may be sought for in the configuration of the continents.

FIG. 513.



The trade-winds may be easily explained. The air that has been strongly heated in the equatorial regions ascends, and rising over the colder masses of air on either side, flows upwards towards the poles, whilst below, it flows from the poles towards the equator. If the earth did not rotate on its axis, the trade-wind in the northern hemisphere would blow directly from north to south, while in the southern hemisphere its direction would be opposite. The earth, however, rotates from west to east, and the atmosphere surrounding it partakes of this rotatory motion.

The nearer a place upon the earth's surface is to the poles, the slower will it move during its twenty-four hours' revolution, because the space it describes diminishes as it recedes from the equator. The rotatory velocity of the mass of air over the earth, is consequently less near the poles than it is at the equator; if then, a mass of air comes from higher latitudes to the equator, it will pass over districts with a less velocity of rotation than that with which these move from west to east; in relation to the places rotating below it, it will, therefore, have a motion from east to west. This motion combines with the motion towards the equator to produce a north-east in the northern, and a south-east wind in the southern hemisphere.

The air which rises in the equatorial regions flows off on either side towards the direction of the poles. The course of the upper trade-wind is naturally directly opposite to that of the lower one, being south-west in the northern, and north-west in the southern hemisphere.

We may prove by facts, that there is actually a trade-wind

in the upper regions of the air; thus, for instance, on the 25th of February, 1835, at an eruption of the volcano of Cosiguina, in the State of Guatimala, the ashes were ejected to the elevation of the upper trade-wind, and were carried by it in a south-west direction, and precipitated on the island of Jamaica, although the north trade-wind was blowing in the regions below.

At a greater distance from the equator, however, the upper trade-wind inclines more and more towards the earth's surface. At the summit of the Peak of Teneriffe, west winds almost always prevail, whilst the lower trade-wind blows at the level of the sea.

In the Indian Ocean, the regularity of the trade-winds is disturbed by the configuration of the land surrounding this sea—for instance, by the Asiatic continent. In the southern part of the Indian Ocean, between New Holland and Madagascar, the south-east trade-wind prevails throughout the year, while a constant *south-west* wind blows in the northern part of this ocean during six months of the year, and a constant *north-east* wind during the remaining period of the year. These regularly alternating winds are called *monsoons.*

The south-west wind blows from April till October, while the north-east wind prevails during the other months.

As during the winter the Asiatic continent is cooled, while a greater heat is engendered in the southern regions, a north-east trade-wind must naturally pass from the colder parts of Asia to hotter regions. At this time too, the north-east trade-wind is separated from the south-west trade-wind in the Indian Ocean, by the region of calms.

During the summer months, the passage of the south-east trade-wind between New Holland and Madagascar, is not disturbed, whilst in the northern parts of the Indian Ocean, the wind that had blown during the winter from the north-east, is now changed into a south-west wind, owing to the Asiatic continent becoming so strongly heated, and a current of air being thus conveyed towards the north, which by the rotation of the earth, is converted into a south-west wind.

Winds in higher latitudes.—The upper trade-wind, which brings the air from the equatorial regions, falls more and more, as has been already mentioned, and finally reaches the earth as a south-west wind; when beyond the region of the trade-winds, the two currents of air that pass from the poles to the equator, and

back from the equator to the poles, no longer blow over, but even with each other endeavouring to replace one another; thus, on the south-west or the north-east wind predominating from time to time, we see on the transition of the wind from one direction to another, the currents of air moving in all points of the weather-cock.

Although the south-west and north-east winds predominate also in higher latitudes, we find no regularly periodic alternation in their occurrence, as is the case with the monsoons in the Indian Ocean.

The following table indicates the frequency of the winds in different countries; giving the number of average times that each wind blows during every one thousand days.

Countries.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.
England	82	111	99	81	111	225	171	120
France	126	140	84	76	117	192	155	110
Germany	84	98	119	87	97	185	198	131
Denmark	65	98	100	129	92	198	161	156
Sweden	102	104	80	110	128	210	159	106
Prussia	99	191	81	130	98	143	166	192
N. America . . .	96	116	49	108	123	197	101	210

Laws of the change of wind.—Although the changes in the direction of the wind appear on a superficial view to be wholly devoid of rule in our regions, attentive observers have long since made the remark that winds generally succeed each other in the following order:

S. SW. W. NW. N. NE. E. SE. S.

This alternation in the winds may be the most regularly observed during the winter. The changes of the barometer and thermometer which are connected with these changes of wind, have been well described by *Dove* in the following words.

"When the *south-west* wind, constantly increasing in force, at length predominates, it raises the temperature above the freezing point; and the snow is consequently converted into rain, whilst the barometer falls to the lowest mark. The wind then veers round to the *west*, and the dense flakes of snow indicate the accession of a colder wind no less than the rapid rise of the barometer, the motion of the weather-cock, and the thermometer. A *north* wind clears the heavens, and a *north-east* wind effects a maximum of cold and of the barometer. This, however, is gradually lowered, and the occurrence of fine cirri

indicate by the direction from which they come the advent of a more southern wind, which is soon felt by the barometer, although the weather-cock may not have experienced any change, and may still be pointing due east. The *southern* wind, however, continues to drive the eastern current downward, and on a decided falling of the mercury, the weather-cock points *south-east*, when the heavens again become gradually overcast, and with the increase of heat, the snow that had fallen with a *south-east* and *south* wind is again converted into rain by the *south-west* wind. The same then begins again, the change from the east to the west course being generally characterised by the occurrence of a short interval of fine weather."

The shifting of wind does not always admit of being as regularly traced, as is indicated above, there being often a recurrence of the wind to its old quarter; this, however, is far more frequently observed in the west than the eastern points of the compass. A perfect change of the wind in an opposite direction, as from south to east, north, or west, is very rarely observed in Europe.

The explanation of this law is obtained by the generalization of the explanation concerning the trade-winds.

If the air from any cause be driven from the poles towards the equator, it will pass from places having but an inconsiderable rotatory velocity to such as possess a greater degree of speed; and its motion will thus acquire an eastern direction, as we have seen in the case of the trade-wind. On the northern hemisphere the winds which arise in the north pass therefore in their gradual progress through the north-east to the east. If an east wind thus arise, it will, if the same causes continue in operation which have driven the air towards the equator, act retardingly upon the polar current; the air will acquire the same speed of rotation as the place over which it passes, and if the tendency to return to the equator still continue, the wind will shift back to the north, when the same series of phenomena will be repeated.

If, however, after the polar current has predominated for a time, and the direction of the wind has become eastern, currents set in from the equator; the east wind will pass from south-east to the south. If the air move from south to north it will reach places having an inconsiderable velocity of rotation with the greatest velocity of rotation of the polar regions nearest the equator; hastening, as it were, in advance of the earth's surface which rotates from west to east, until the southern direction of the wind

is gradually changed to the south-west, and finally made quite western. By the constant tendency of the air to pass towards the poles, the wind is made to veer back again to the south, exactly in the same manner as the east wind veers to the north; if, however, the equatorial current be displaced by a current from the poles, the west wind will veer from north-west round to the north.

In the southern hemisphere, the wind must necessarily veer about in an opposite direction.

Where the trade-winds blow in the tropics, there is no complete rotation on the earth's surface, the direction of the trade-wind is, therefore, only inclined more towards the east in its motion.

In the region of the monsoon there is only one complete rotation in the course of the whole year. We, therefore, see that the relations of the winds in the tropics correspond to the simplest case of the law of rotation.

Storms.—Storms are the result of a considerable disturbance in the equilibrium of the atmosphere, depending very probably upon a rapid condensation of vapour, as has already been surmised.

More recent investigations have shown that storms may, for the most part, be regarded as great whirlwinds in motion.

Storms rage with much more violence in the tropics than in higher latitudes; the devastations occasioned by these hurricanes, known in America by the name of *Tornadoes*, are truly frightful. Thus, for instance, in the hurricane that devastated Guadaloupe on the 25th of July, solidly-built houses were torn up; cannons were hurled from the top of the parapets of the batteries on which they were planted; a plank of about 3 feet in length, 8 inches in breadth, and 10 lines in thickness, was propelled with such force through the air that it perforated the stem of a palm tree, about 17 inches in diameter, through and through.

We often see how, in calm weather, sand and dust are carried by the wind with a whirling motion through the air. On the approach of a storm, we may also notice larger whirlwinds of this kind carrying sand, dust, leaves and straw, &c. with them in their course. Hurricanes are nothing more than these whirlwinds on a large scale, and are generally caused by the struggle of two winds moving in opposite directions in the upper regions of the air. They usually form a double cone, the upper

part of which, whose vertex inclined downwards, consists of a mass of clouds; while the lower cone, the point of which is directed upward, when formed over the sea, lakes and rivers, is composed

FIG. 514.

of water or of sand, and other bodies found on land. These hurricanes are capable of uprooting trees, unroofing houses, and hurling beams to a distance of many hundred paces, &c. Water hurricanes are known as *water spouts;* they often raise water to the height of many hundred feet.

CHAPTER III.

OF ATMOSPHERIC MOISTURE.

Distribution of vapour in the air.—If on a hot summer's day we place a bowl filled with cold water in the open air, we observe that the quantity of the water rapidly diminishes,—that is, it evaporates, which means that it is converted into vapour, and then diffused through the air. The vapour of water is, like every other colourless transparent gas, invisible to our eyes, the water appearing to have entirely disappeared by evaporation.

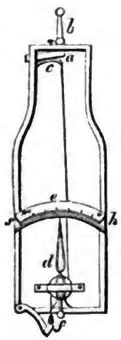
The water diffused through the air only becomes visible, when,

on returning to its fluid condition, it forms a mist, cloud, dew, or hoar-frost. In order, therefore, to convince ourselves of the existence of vapour of water in the air, we must condense it by some means or another.

We may immediately obtain the quantity of vapour contained in a definite volume of air, on sucking the air through a tube filled with hygrometric substances. We make use of an *aspirator* for the purpose of effecting a regular passage of the air through the absorption tube. The aspirator is a vessel filled with water, and closed, excepting at two apertures; from the one of which water constantly pours out through a tube, while the other is connected with the absorption tube in such a manner, that an amount of dry air equal to the discharged water may enter the vessel. The amount of vapour contained in a quantity of air sucked through the absorption tube may be ascertained by weighing the tube before and after the experiment.

This method of determining the quantity of water contained in the air entering the aspirator, to which various forms, more or less applicable, have been given, is somewhat uncertain, and does not yield the amount of water contained in the air at a definite moment, but merely the mean average of its quantity during the whole period of the experiment; on this account, smaller and more easily transportable apparatus have been constructed, which are known by the name of *hygrometers*.

FIG. 515.



It is well known that many organic bodies have the property of absorbing vapour, and thus increasing proportionably in extent. Amongst others, we may mention hair, whalebone, &c., as hygrometric bodies, and these have therefore been employed in the construction of hygrometers. The best instrument of the kind is the *Hair-hygrometer* invented by *Saussure*, and which is represented in Fig. 515.

The hair is fastened at its upper end to a little tongue *a*, the other extremity passes over along one of the two grooves of a pulley, while in the other groove a silk thread goes round the pulley, supporting a little weight *f*, by means of which the hair is kept at a constant tension. To the axis of the pulley, an index *d* is attached, which passes over the

graduated arc *s h*, as the pulley is turned by the elongation or shortening of the hair.

When the instrument is in a damp atmosphere, the hair absorbs a considerable amount of vapour, and is thus made longer, while in a dry air it becomes shorter, so that the index is of course turned alternately to the one or to the other side.

The instrument is graduated in the following manner. In the first place, it is placed under a receiver, the air within having been dried by chloride of calcium or by sulphuric acid. The point of the scale at which the index stops, under these circumstances, is the point of greatest dryness, and is marked with 0.

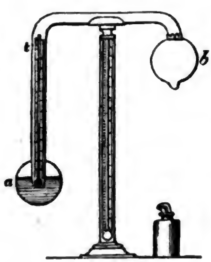
The instrument is then placed under a receiver, whose walls are moistened with distilled water, which is likewise poured upon the ground, on which the receiver is placed. The space below it soon becomes saturated with vapour, and the index then passes to the other end of the scale. The point at which it now stands, is the point of greatest moisture, and is marked 100.

The space intervening between these two points must then be divided into 100 equal parts, which are termed *degrees of moisture*.

The relation of these degrees to the quantity of water in the air must, in the case of every instrument of the kind, be ascertained by means of experiments, into which we cannot enter more fully at present.

Daniel's Hygrometer.—Is represented in Fig. 516; it consists of a curved tube terminating in two bulbs; the one *a* is either gilt, or covered with a thin metallic coating of platinum, while the other is wrapped in a piece of fine linen. The bulb *a* is half filled with ether, and contains a little thermometer, the graduated part of which penetrates into the tube *t*. The apparatus is perfectly air-tight. If ether be dropped upon the ball *b*, it will cool it by its evaporation; in the interior the vapour of the ether will be condensed, and an evaporation in the bulb *a* thus occasioned, since, to a certain degree, the ether distills over from the warmer ball *a*, to the cooler one *b*. By the formation of vapour in the ball *a*, heat will be likewise absorbed,

FIG. 516.



and the bulb become covered with a delicate dew. The origin of this dew admits of an easy explanation. We have seen above, that in a vacuum, the force of tension of steam cannot exceed certain limits, and that the maximum of the tension increases with the temperature. For a temperature of 68^0, for instance, the maximum of the force of tension of steam is 17,3 millimetres, and the corresponding density of the steam 0,00001718; in a vacuum of 1 cubic metre, therefore, at a temperature of at most 68^0, 17,18 grms. of water may be contained in the form of vapour.

We have, however, further seen, that exactly as much steam may be contained in a space filled with air as in an equally large vacuum, and that in this case the force of tension of the air, and the force of tension of the steam diffused through it correspond. At a temperature of 78^0, 17,8 grms. of water may therefore be contained as vapour in 1 cubic metre of air.

We say the air is *saturated* with vapour, when the steam diffused through it has reached the maximum of the force of tension and density corresponding with its temperature.

If we bring a colder body into an atmosphere saturated with moisture, it will cool the strata of air most contiguous, a portion of the vapour contained will be condensed, and precipitated upon the cold body in the form of fine drops. In this manner the moisture which covers the window panes of an inhabited heated apartment is formed; if the temperature of the external air be low enough, sufficiently to cool the panes of glass.

The air is not always saturated with moisture, that is to say, it does not always contain as much vapour as from its temperature it might take up. If, for instance, we assume that every cubic metre of air contains only 13,63 grms. of steam at a temperature of 78, the air will not be saturated, since at this temperature, each cubic metre of air is capable of containing 17,18 grms. of vapour.

The temperature at which the condensation of steam begins, that is, the temperature at which the air is exactly saturated with vapour, is called the *dew point*.

Daniel's Hygrometer is intended for the observation of this dew point; thus, as soon as the bulb *a* is cooled to the temperature of the dew point, this bulb begins to be covered with moisture, and the temperature of the dew point may be immediately ascertained from the thermometer which dips into the bulb *a*.

If we now make use of a table giving the maximum quantity of vapour of water in a space of 1 cubic metre for each degree of temperature, we may likewise find by means of such a table, what is the quantity of vapour of water in the air corresponding to the dew point observed.

August's Psychrometer is represented in Fig. 517, it consists of two thermometers fastened to one and the same stand: the bulb of the one is surrounded by fine linen, whilst that of the other remains free; on moistening with water the covering of the one bulb, the water will evaporate, and the more rapidly in proportion as the air is far removed from its point of saturation. The evaporation of the water is, however, accompanied by an absorption of heat, in consequence of which the covered thermometer falls. If the air be perfectly saturated with moisture, no water will be able to evaporate, both temperatures therefore will stand equally high; if, however, the air be not thoroughly saturated with vapour, the covered thermometer will fall lower in proportion as the air is further removed from the point of saturation. We may judge of the condition of moisture of the air by the difference of temperature of the two thermometers.

FIG. 517.

Diurnal and annual variation in the quantity of water contained in the air.—As more vapour may be diffused through the air at a high temperature, and as with an increasing heat the water evaporates more and more from the surface of large masses of water and from the moist ground, it may well be supposed that the quantity of water contained in the air will diminish and increase in the course of the day.

It has been ascertained by experiments with the above-described instruments, that in general, the quantity of vapour in the air is increased as the temperature rises with the ascent of the sun; this, however, only lasts till 9 o'clock, when an ascending current of air, occasioned by the strong heating of the surface of the ground, carries the vapour on high, so that the water contained in the lower strata of air diminishes, although the formation of vapour continues with the increase of the heat; this diminution continues till towards 4 o'clock; now the quantity of water of the lower strata of air again increases, because the

upwardly directed current of air ceases to carry away the vapour formed; this increase lasts, however, only until towards 9 o'clock, because the decreasing temperature of the air puts a limit to the further formation of vapour.

In winter, when the action of the sun is less intense, the state of the case is different; in January we observe only *one* maximum of the contents of water in the air, at about 2 o'clock, and only *one* minimum at the time of sunrise.

We say "*the air is dry*" when water evaporates rapidly, and when moistened objects become quickly dry owing to this rapid evaporation; and on the other hand, we say "*the air is damp*" when moistened objects dry only slowly, or not at all, in the air, when the least decrease of temperature occasions a precipitation of moisture, and when somewhat colder objects become covered with moisture. We, therefore, call the air dry when it is far from being at its point of saturation, and moist when the dew point approaches very nearly to the degree of the temperature of the air; in thus judging of the dryness or the dampness of the air, we do not, therefore, express any opinion of the absolute quantity of water contained in the air. If on a hot summer's day at a temperature of 77, every cubic metre of air contains 13 grms. of vapour, we say the air is very dry; for at such a temperature the atmosphere can contain 22,5 grms. of vapour for every cubic metre of air, otherwise the air must be cooled to 59, in order to be saturated by the same quantity of aqueous vapours. If, on the contrary, in winter at a temperature of 35,6 the air contains only 6 grms. of vapour, it is very damp, since the atmosphere is nearly perfectly saturated with vapour corresponding to that temperature, and the least decrease of temperature is followed by a precipitation of moisture.

In this sense we may say, that at the time of sunrise the air is the dampest, although the absolute quantity of water is less then than at any other time of the day. Towards 3 o'clock P.M. in summer the air is driest.

The absolute quantity of water contained in the air is, like the mean temperature of the air, at a minimum in January; it increases until July, when it reaches its maximum; then, however, it again decreases until the end of the year.

Although the quantity of water contained in the air is greater in summer than in winter, we say that the air is drier in summer,

because, on an average it is further removed from the point of saturation during that season.

Moisture of the air in various districts.—The formation of vapour is especially dependent upon two conditions, namely upon the temperature, and upon the pressure of water. With an unlimited supply of water, vapour will be formed in proportion to the height of the temperature; but with equal degrees of temperature, more vapour will be formed in districts which abound in water than in those which do not. Hence, it follows, that the absolute quantity of water in the air, other circumstances being the same, decreases from the equator to the poles, and that the air is drier in the interior of large continents, that is, it is there further removed from the point of saturation than on the sea or on the sea-shore. The clearness of the sky in continental countries is a proof that the dryness of the air increases with the distance from the sea.

Dew.—It has already been stated at page 533, that fine dew is formed upon the polished bulb of *Daniel's* hygrometer as the latter is cooled. We may explain the formation of dew on a large scale in a similar manner.

When in summer, after sunset, the sky remains clear and the air calm; the different objects on the earth's surface become more and more cooled by nocturnal radiation towards the sky, their temperature falls from 4^0 to 13^0, or 14^0 even below the temperature of the air, cold bodies also lower the temperature of the strata of air immediately surrounding them; and when these are cooled down to the dew point, a portion of the vapour contained in them is precipitated upon cold bodies in the form of fine drops.

As all bodies have not an equal capacity of radiating heat, some cool more perfectly than others, whence it follows, that many bodies may be densely covered with dew, whilst others will remain almost wholly dry. Grass and leaves, especially, cool rapidly by nocturnal radiation, partly because they possess a very strong capacity for radiation, and partly also because they stand exposed to the air, and can thus receive but little heat from the ground; they are thus more thickly covered with dew than stones and the bare ground.

When the sky is overcast by clouds, the formation of dew is prevented, owing to nocturnal radiation being impeded. Even

when a somewhat brisk wind blows, no dew is formed, because warm air is constantly brought into contact with solid bodies, which are thus continually warmed, and allow of air passing over them before they can be cooled to the dew point.

Hoar-frost is nothing but frozen dew. When the body, on which the condensed vapour is precipitated, is cooled below 32°, vapour can no longer be deposited in a fluid form, but will appear as icicles.

Mist and clouds.—When steam rises from a vessel of boiling water, and diffuses itself through a cooler atmosphere, it is immediately condensed, and there arises a *mist* in the air which floats about in the form of a quantity of small hollow vesicles. This is also frequently called vapour, although it is no longer such, at least, in the physical sense of the word, being a condensed aqueous gas.

When the condensation of vapour does not occur by contact with cold solid bodies, but goes on in the air, *mists* arise, which are similar to those we see formed over boiling water.

Mists generally arise when the water of lakes and rivers, or the damp ground, is warmer than the air which is saturated with moisture. The vapours formed in consequence of the higher temperature of the water, or the damp ground, are immediately re-condensed, when they diffuse themselves through the cooler air, already saturated with vapour. No mists are formed at an equal difference of temperature between the water and air, provided the air is dry, so that all the vapours rising from the surface diffused themselves through it without saturating it.

After what has just been said of the formation of mist, it will easily be understood that mists are especially formed in autumn over rivers and lakes, and damp meadows. In England, mists are very frequent, from the land being washed by a warm sea; in like manner, the warm waters of the Gulf Stream, which flows as far as Newfoundland, are the cause of the thick fogs met with there.

We often observe mists and fogs occur under totally different circumstances; thus we find thick mists over rivers, whilst the air is warmer than the water or the ice. In this case, the warm air is saturated with moisture, and on its mixing with the layers of air, which have acquired a lower temperature from being in contact with the cold water or ice, a condensation of the vapour is necessarily brought about.

The mists which rise over rivers and lakes in summer after a storm of rain, originate in a similar manner. Although the air is warmer than the surface of the water, it is saturated with moisture, and as soon as it is distributed over a place in which the freshness of the water is perceptible, the vapour becomes condensed by cooling.

Mists are not, however, formed only over rivers and lakes, but over the middle of the continent, as soon as the warmer, damper masses of air are mixed with the colder, and their temperature thus lowered below the dew point.

Clouds are nothing more than mists, which hover in the higher regions of the air, as mists are nothing more than clouds resting upon the surface of the ground. We often see the summits of mountains enveloped in clouds, whilst persons upon these elevations are in the midst of mist.

At first sight, it appears incomprehensible how clouds can float in the air, since they consist only of vesicles, which are evidently heavier than the surrounding air. Since the weight of these small vesicles of water is very small in comparison with their surfaces, the air must, in this case, oppose a considerable resistance; they can only sink very slowly, as the soap bubble, which has a great resemblance to these vesicles of vapour, sinks but slowly in a calm atmosphere. These vesicles of vapour must, however, sink, although but slowly, and we might thus suppose that in calm weather the clouds would, at length, fall to the ground.

The vesicles of vapour, however, which sink in calm weather, cannot reach the ground, owing to their soon reaching warmer strata of air that are not saturated with vapour, and where they again dissolve into vapour, and are lost to view; whilst, however, the vesicles of vapour dissolve below, new ones are formed at the upper limits, and thus the cloud appears to float immoveably in the air.

We have just considered vesicles of vapour in a perfectly calm atmosphere, but when the air is agitated they must follow the direction of the current of air; a wind moving on in a horizontal direction will also carry the clouds with it in the same direction, and an ascending current of air will lift them up, as soon as its velocity becomes greater than the velocity with which these vesicles would fall to the ground in a calm air. We may also observe how soap bubbles are carried away by the wind, and

borne over the houses. Thus too, the rising of the mist is explained by the ascending currents of air.

The appearance of the clouds varies very much, according as they float higher or lower, are more or less dense, and are differently illuminated, &c. *Howard* has distinguished clouds under the following heads.

1. The feathery cloud-*cirrus* consists of very delicate, more or less streaked, open or feathery filaments, which first appear in the sky after fine weather. In our figure 518, we may observe these in the right hand corner towards the bottom where the two birds are hovering. In dry weather, feathery clouds are more streaked, and in damp weather more confused.

2. The dense cloud, *cumulus*, represented in our figure exactly

FIG. 518.

below the feathery cloud, forms large hemispherical masses which appear to rest upon a horizontal basis; these clouds are of most frequent occurrence in summer, often group themselves picturesquely together in large masses, and then, when lighted up by the sun, present the appearance of mountains of snow.

3. *Stratified clouds, stratus,* are horizontal streaks of clouds; in our figure they are represented below the *cumulus,* and appear in extraordinary brilliancy of colour at sunset.

The main forms merge into a variety of others, which *Howard* has designated by the names of *cirro-cumulus, cumulo-stratus,* and *nimbus.*

The feathery accumulated cloud, the *cirro-cumulus* is the transition of the feathery to the dense cloud, they are those small, white, round clouds familiarly known as *fleecy.*

When the feathery clouds are not scattered individually, but combined in streaks of considerable extension, they form feathery strata of clouds, *cirro-stratus,* which offer the appearance of expanded strata when they are near the horizon; the *cirro-status* often cover the whole sky as with a veil.

When these clouds become denser, they pass over into the streaked accumulated clouds, which often cover the whole horizon with a bluish black tone of colour, and finally pass over into the actual *rainy cloud* (*nimbus*) depicted at the left in our figure.

When we consider how very various the clouds may be in form as well as in colour, we shall easily understand how difficult it often is to decide whether the appearance of a cloud approaches more to one or other type.

The feathery clouds are the highest of all the kinds of clouds, since they present the same appearance when seen from high hills as from the valleys below. *Kämtz** determined their height at Halle to be about 20,000 feet. It is highly probable that the *cirrus* does not consist of vesicles of mist, but of flakes of snow.

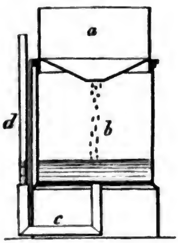
The denser clouds are usually formed when the vapours are raised up by the ascending currents of air, and then condensed by the lower temperature. Hence, it follows, that clouds often form towards noon, when the sun has ascended in the clear sky; and towards evening the sky again clears, owing to the sinking of the clouds as the rising current ceases; the clouds again dissolve on reaching deeper, warmer regions, if the air be not saturated with vapour. As, however, the south-west wind brings more and more vapours with it when the air is saturated with vapour, the sinking clouds cannot be re-dissolved, but become denser and darker, whilst a stratum of feathery clouds often floats above the lower clouds. The lower masses of cloud-cumulus then pass more and more into the *cumulo-stratus,* and rain may be expected.

* See "Complete Course of Meteorology," page 365.

When by continued condensation of vapour, the separate vesicles of vapour become larger and heavier, when further, the separate globules approach each other and merge together, they form actual drops of water, which fall as rain. At a certain height the rain-drops are still very small, they increase in size, however, as they fall, owing to the vapour of the strata of air becoming condensed on which account they fall.

Quantity of rain.—The quantity of rain which falls at any one spot on the earth in the course of the year is a very important element of meteorology. The instruments made use of for this purpose are termed *Rain guages, Ombrometers* or *Udometers.* Fig. 519 represents the usual rain guage; it consists of a tin cylinder *b,* which is from 15 to 20 centimetres in diameter, and on which a second cylinder *a,* with a funnel-like bottom, is placed. In the centre of this funnel there is an aperture; through which all the water, falling into the cylinder *a,* which is open at the top, flows into the receiver *b.* The receiver *b* is in connection by means of a curved tube *c* with a glass tube *d,* by means of which we may every time ascertain how high the water stands in *b.* Provided that the bores of *a* and *b* be equal, or at any rate not perceptibly different, the height of the layer of water in *b* indicates the height to which the ground would be covered in a certain time, if the water were not imbibed, or evaporated.

FIG. 519.



The annual quantity of rain is about as follows:

at Lisbon . . .	25	Paris inches.
Dover . . .	44	„
London . .	23	„
Paris . . .	21	„
Ratisbon . .	21	„
Bergen . .	83	„
Stockholm .	19	„
Petersburgh .	17	„
Genoa. . .	44	„
Rome . . .	29	„

The quantity of rain that falls, is not, however, uniformly

distributed throughout the year; in this respect, Europe admits of being divided into three provinces.

In England, on the western coasts of France, in the Netherlands, and in Norway autumnal rains predominate.

In Germany, in the West-Rhenish provinces, Denmark and Sweden, rains are most prevalent in summer.

Rains scarcely ever fall during summer in the south-east of France, in Italy, the south of Portugal, or in that part of Europe which is most contiguous to Africa.

In Europe, the number of *rainy days* during the year generally decreases from south to north. On the average through the year there are about as follows:

in southern Europe	. .	120 rainy days.
„ central „	. .	146 „
„ northern „	. .	180 „

That the quantity of rain does not alone depend upon the number of rainy days is evident, since it matters not how many days, but how much it rains; although the number of rainy days increases in northern districts, the intensity of the rain generally diminishes, and thus we see why in St. Petersburg, for instance, the number of rainy days is in general greater, although the quantity of rain that falls is less.

The quantity of rain, as well as the number of rainy days, decreases with the increased distance from the sea; thus, for instance, there are about as follows:

in St. Petersburg	. . .	168
„ Casan	. . . . .	90
„ Jakutzk	. . . .	60

rainy days in the course of the year.

As under equal circumstances rain in warmer districts is more intense than in colder, it is also more intense in the warmer than in the colder season of the year. There are on an average 38 rainy days in Germany in the winter, and 42 in the summer; the number of the rainy days in summer is therefore scarcely more considerable than in winter, and yet, the quantity of rain in summer is about double as great as in winter. In the summer months there often falls more rain in a single storm than during many weeks.

Rain between the tropics.—Where the trade-winds blow with the greatest regularity, the sky is for the most part clear, and it

seldom rains; that is, when the sun stands above the other hemisphere. On continents, however, the regularity of the trade-winds is disturbed by the intensity of the ascending current of air as soon as the sun approaches the zenith; about this time a violent rain sets in, which lasts many months, whilst during the remainder of the year the sky is uniformly clear, and the air dry.

Humboldt has described the phenomena of the rainy season in the northern part of South America. From December till February the air is dry, and the sky clear. In March the air becomes more humid, the sky less pure; the trade-winds then blow less strongly, and the air is often quite calm. By the end of March, the storms set in; they begin in the afternoon, when the heat is greatest, and are accompanied by violent torrents of rain. Towards the end of April, the actual rainy season begins, the sky is overcast with a uniform gray tint, and it rains daily from 9 A.M., till 4 P.M.; at night the sky is mostly clear. The rain is the most violent when the sun is in the zenith. The time during the day in which it rains then becomes gradually shorter, and towards the end of the rainy season it rains only in the afternoon.

The length of time of the rainy season is not the same for different districts, but lasts, generally speaking, from 3 to 5 months.

In the East Indies, where the regularity of the trade-winds is disturbed by local influences, and where the monsoons take their place, we also find irregularities in the quantities of rain. On the steep western coasts of India, the rainy season corresponds with our winter, occurring at the time when the south-west monsoons prevail, and, being laden with humidity, strike the high mountains. Whilst it rains upon the coasts of Malabar, the sky is clear in the eastern shores of Coromandel; here the rainy season comes in with the north-east trade-wind, that is, exactly at the time when the dry season prevails upon the western coasts.

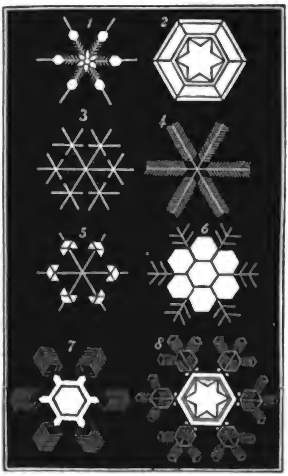
In the region of calms, periodical rains do not prevail; but violent torrents of rain are of almost daily occurrence. The ascending current of air carries a mass of vapour on high, which again condenses in the colder regions. The sun almost always rises with a clear sky, but towards noon a few clouds are formed, which become denser and denser, until at length an immense quantity of rain falls,

amid violent gusts of wind and electrical discharges. Towards evening the clouds disperse, and the sun sinks in a clear sky.

The annual quantity of rain that falls in the tropics is in general very great; it amounts in Bombay, for instance, to 73,5, in Candi to 68,9, in Sierra Leone to 80,9, at Rio Janeiro to 55,6, at St. Domingo to 100,9, at the Havanna to 85,7, and in Grenada to 105 Paris inches. If we now consider that rain is generally limited to a few months, and that it only rains during a few hours of the day, it is evident that the rain must be very violent. At Bombay there fell in one day 6 inches of rain, at Cayenne 10 inches in 10 hours. The drops are very large, and fall with such rapidity, that they give rise to a sensation of pain if they strike against the skin.

Snow and Hail.—Even at the present time we know very little regarding the formation of snow. It is probable that the clouds in which the flakes of snow are first formed, consist, not of vesicles of vapour, but of minute crystals of ice, which by the continuous condensation of vapour become larger, and then form flakes of snow, which continue to increase in size while falling through the lower strata of air. When these lower regions are too warm, the flakes of snow melt before reaching the ground, so that it rains below while it snows above.

FIG. 520.



The regular form assumed by flakes of snow, in the state which they can be best observed, namely, when they are placed on a dark body cooled below 32°, was first described by *Kepler*. *Scoresby* had an opportunity, in the polar regions, of making a number of interesting observations on the forms of the flakes. His work contains nearly 100 different plates, of which some of the most interesting have been collected in Fig. 520.

A mere superficial glance at these figures shows that all their forms are essentially referrible to a regular hexagonal star, from whence it follows that snow-flakes belong to the hexagonal system of crystals (the crystal-system of rock crystals).

Sleet, which we usually observe in March and April, is formed in the same manner as snow. The granules of sleet are formed of tolerably firm spherical icicles.

Hail is one of the most fearful scourges to the agriculturist, and one of the most mysterious phenomena to the meteorologist.

The ordinary size of hail-stones is that of a hazel nut; they are very frequently smaller, but these, being less dangerous, are not particularly regarded. They are often, however, much larger, and destroy everything they strike.

Trustworthy pilosophers have observed hail-stones which weighed 12 to 13 ounces.

The form of hail-stones is liable to great variation; most commonly they are rounded, but sometimes flattened and angular. In their centre there is usually an opaque nucleus, resembling a granule of sleet: this nucleus is surrounded by a transparent mass of ice, in which we may often observe separate concentric layers; sometimes alternating layers of transparent and opaque ice may be seen; and, finally, even hail-stones with a striated structure have been observed.

Pouillet found that the temperature of hail-stones varied from 31 to 25°.

Hail generally precedes a thunder-storm. It never, or at any rate but very rarely, follows rain; at least, when the latter has continued some time.

A hail-storm generally lasts only a few minutes, very seldom so long as a quarter of an hour. The quantity of ice which escapes from the clouds in so short a time is enormous; the earth being often covered by it to the depth of several inches.

Hail falls more frequently by day than by night. The clouds which bring it seem to have a considerable extension and depth, for they generally occasion great darkness. It is believed that they have been seen of a peculiar greyish red tint, and that great masses of clouds were suspended from their lower confines, and their edges variously indented.

Hail-clouds seem generally to float very low. The inhabitants of mountainous districts often see clouds below them which cover the valleys with hail; it cannot, however, be determined with accuracy whether hail-clouds always descend so low.

A peculiar rustling noise is heard a few seconds before the beginning of a hail-storm; and, finally, hail is always accompanied by electrical phenomena.

As to what concerns the explanation of hail, this presents two difficulties: namely, as to whence the great cold comes, which causes the water to freeze; and next, how it is possible that the hail-stones, after having once become large enough to fall by their own weight, can yet remain long enough in the air to increase to so considerable a size.

With regard to the first question, *Volta* thought that the solar rays were almost wholly absorbed at the upper confines of the dense clouds, which would necessarily occasion a rapid evaporation, especially when the air above the clouds was very dry; this evaporation would, according to him, cause so much heat to be absorbed, that the water in the lower strata of air would freeze. If, however, the evaporation of the water in the upper stratum of air were occasioned by the heat of the solar rays, it is not so clear why so much heat should be withdrawn from the lower layers of clouds by means of this evaporation.

With reference to the second question, *Volta* proposed a very ingenious theory, which has attained great celebrity. He assumes that two layers of clouds, heavily charged with opposite kinds of electricity, hover above one another. If now the very small hail-stones fall upon the lower clouds, they will penetrate to a certain depth, and thus become surrounded by a new layer of ice; they will, however, also become charged with the electricity of the lower cloud, and be repelled by it, while they will be attracted by the other; they will therefore again rise, in spite of their gravity, to the upper cloud, where the same process will be repeated; thus they will move for a time backwards and forwards between the two clouds, until at last they will fall, when they become heavy enough, and when the clouds have lost their electricity.

It may be objected to this view, that it is scarcely conceivable that electricity is able, without any sudden action, that is, without any explosive discharge, to raise such large masses of ice; and that if the electric charge of the two clouds were really so powerful, the electricity must instantaneously pass from one to the other: especially since the hail-stones must establish a connection between them.

CHAPTER IV.

OPTICAL PHENOMENA OF THE ATMOSPHERE.

Colour of the sky.—The clear sky appears to us to be *blue,* and this blue is sometimes brighter and whiter, and sometimes darker, according to the state of the atmosphere; on high mountains the sky appears dark blue, or almost black. This is readily explained: if the air were perfectly transparent, if its individual particles reflected, or rather scattered no light, the sun, moon, and stars would shine out forth from a black ground; but, as it actually is, the particles of air reflect the light, and thus it happens that during the day the whole sky appears bright, because the particles of air illuminated by the sun scatter the light in all directions. This illumination of the atmosphere by the sun's rays is the cause of our not seeing the stars during the day. The particles of air reflect mostly blue light, and hence it is that the dark vault of heaven is invested with a blue tint. The higher we rise in the atmosphere, so much the thinner is the blue envelope, and consequently so much the darker does the heaven above us appear; thus the darkest blue is always in the zenith, while towards the horizon there is more of a whitish tint.

The pure blue of the sky is especially decolourized by the condensed vapour floating in the air, by fine mists, which often invest the sky as with a delicate veil, without being sufficiently dense to appear as clouds.

The phenomena of the evening and morning red are explained by saying that the air permits of the passage of the red and yellow rays in preference, but that it reflects the blue rays. The sun's rays in the evening and morning have to traverse a considerable space through the atmosphere, hence the red colouring of the transmitted rays, which is particularly brilliant when clouds are illuminated by them.

This opinion cannot be altogether correct,because the blue tint of the sky is not the complementary colour of the evening red. The evening red depends probably on the vapour of water contained in the air.

When a column of steam rises from the safety-valve of a steam-engine, as, for instance, of a locomotive, the sun seen through the

steam appears of a deep orange red; some feet above the safety-valve, at which the steam is escaping, its colour by transmitted light has the deep orange tint already described; at a greater distance, where the vapour is more perfectly condensed, the phenomenon entirely disappears. Even a moderately thick cloud of vapour is perfectly impenetrable to the sun's rays, it throws a shadow like a solid body; and when its thickness is small, it is then indeed transparent, but colourless throughout. The orange colour of vapour appears, therefore, to pertain to a peculiar state of condensation. In a perfectly gaseous state, aqueous vapour is quite transparent and colourless; in any transitive state, it is transparent and of a dingy red; but when it is perfectly condensed into vesicles of mist, a thin layer is transparent and colourless, while a thick layer is perfectly opaque.

Aqueous vapour, being a pure, colourless, elastic fluid, gives to the air most of its transparency, particularly as is observed when the sky clears after a severe rain. In the transition stage, it admits of the passage of the yellow and red rays, and in this condition gives rise to the appearance of the evening red.

This theory will also explain why it is that the evening red is far more brilliant than the morning red; that the evening red and the morning gray are signs of fine weather. Immediately after the maximum diurnal temperature has been attained, and before sunset, the surface of the earth and strata of air at different heights begin to lose heat by radiation. Before, however, this has led to the entire condensation of the aqueous vapour, it passes through that transition stage which causes the evening red. In the morning the case is different. The vapours which in the reversion of the process would probably have given rise to the red, do not rise till they have been exposed sufficiently long to the sun's action, but then the time of the sun's rising is over, and the sun stands high in the heavens. The fiery appearance of the morning sky depends on the presence of such an excess of moisture, that by its condensation in the higher regions actual clouds are formed, notwithstanding the tendency of the rising sun to disperse them; the morning red is therefore to be considered as the forerunner of speedy rain.

When the sun has disappeared in the western horizon, instead of there being immediate darkness, we have the twilight, which lasts, under different circumstances, for a longer or shorter time. The twilight is produced by the sun's continuing to shine on the atmosphere of the western sky, and on the aqueous particles suspended

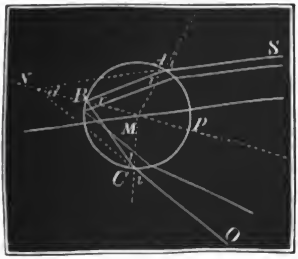
in it, for some time after it has disappeared from our view, and on these illuminated particles of air and water continuing to transmit to us a light which becomes gradually fainter and fainter. In Germany and countries of the same latitude the twilight lasts till the sun is about 18° below the horizon. The prolonged duration of twilight in higher latitudes is dependent on the circumstance that the sun's orbit is there very strongly inclined towards the horizon, and that consequently it takes a very considerable time for the sun to sink 18° below it. The nearer we approach to the equator, so much the less oblique is the sun's orbit towards the horizon, until under the equator the two are at right angles; in hot countries the twilight is therefore of shorter duration. In Italy it is shorter than in Germany, in Chili it lasts only a quarter of an hour, and in Cumana only a few minutes. This extremely short twilight is not solely to be referred to the direction of the sun's orbit with respect to the horizon; we must also take into consideration the extraordinary purity of the sky in those countries, for in our regions the delicate mists which float high in the air, and during the day veil the sky, materially assist in reflecting the light and so prolonging the twilight.

The rainbow.—Every one knows that we see a rainbow when we have the sun behind us and face a showery cloud. The rainbow forms the base of a cone, whose vertex is the eye, and whose axis coincides with the straight line passing through the sun and the eye. Under the above conditions the rainbow appears in the mist of waterfalls and fountains.

In order to explain the formation of the rainbow, we must follow the course of the sun's rays through a drop of rain.

If a ray $S A$ (Fig. 521) strikes a rain-drop, it is refracted, and it is easy to calculate or to construct the direction of the refracted ray $A B$. The refracted ray $A B$ is reflected at B, by the posterior wall of the drop to C, and then after a second refraction emerges in the direction $C O$. The emergent ray $C O$ forms with the incident ray an angle $S N O$.

FIG. 521.



But many other rays fall on the drop parallel with $S A$; and if we calculate or construct for each of them their path through the drop, as we have done in the figure

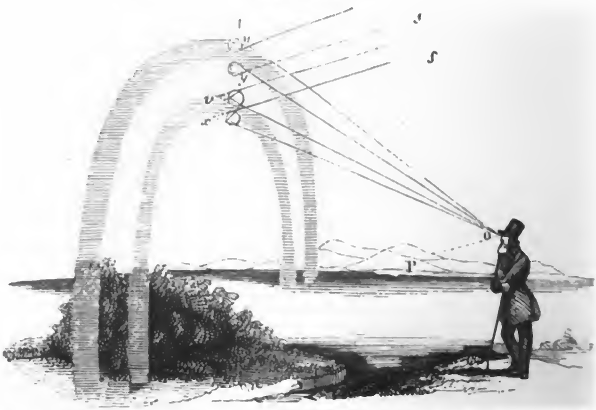
for a second ray, it will be found that the emergent rays are not parallel to one another.

While, therefore, a parallel pencil of light falls on the drop, a pencil of light strongly divergent emerges from it. It is easy to understand, that by this divergence of the rays emerging from the drop, the strength of the impression of the light which they produce is very much weakened, especially when the drops occur at only a slight distance from the eye. Of all the rays which enter the eye from a drop after two refractions and one reflection, those only can make that perceptible impression of light for which the divergence is a minimum, or, in other words, only those which emerge very nearly parallel.

From more accurate examination, it follows that a considerable number of parallel incident rays fall or leave the drop nearly in the same direction, having suffered a deviation of very nearly $42^0\ 30'$; and of all the rays emerging from the drop, these alone can produce a sensible impression of light.

Let us suppose a straight line *o p* (Fig. 522) to be drawn

FIG. 522.



through the sun and the eye of the observer, and a vertical plane to be carried through it. If through *o* we draw the straight line *o v*, so that the angle $p\ o\ v = 42^0\ 30'$, then the rain-drops in this direction will send effective rays to the eye after an internal reflection. The eye, however, does not receive effective rays from this direction alone, but, as may easily be conceived, likewise from all the drops of rain which lie on the surface of the cone,

which arises from the revolution of the line *o v* about the axis *o p*; the eye will, therefore, see a circle of light, the central point of which lies upon the straight line drawn through the eye, and whose radius appears under an angle of 42^0 30′.

In the direction mentioned we observe a circle, which appears as a red ring, about 30′ in breadth, in consequence of the sun not being a mere point, but a disc, whose apparent diameter is 30′. But as the effective violet rays emerge in a direction making an angle of 40^0 30′ with the incident rays, the eye perceives a violet ring about 30′ broad, whose radius amounts to only 40^0 30′. Between these external arcs we observe the other prismatic colours, and thus the rainbow forms as it were a spectrum extended into a circular arc. The whole breadth of the rainbow averages 2^0, since the radius of the red bow is 2^0 greater than that of the violet.

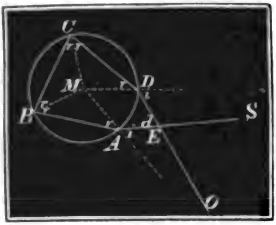
The extension of the coloured arc obviously depends on the sun's altitude above the horizon. When the sun is fast going down, the rainbow appears in the east, the centre of the bow then lying exactly in the horizon, since the line drawn through the sun and the eye is then a horizontal line; when the observer stands on a plane, the rainbow then forms an exact semi-circle; he can, however, see more than a semi-circle, if he stand on an isolated mountain-top of small breadth. At sun-rise the rainbow appears in the west. In proportion to the height of the sun, so much the lower is the centre of the coloured bow below the horizon, and consequently so much the smaller is the portion of the bow visible to the eye. If the sun's elevation above the horizon is 42^0 30′, no rainbow is any longer visible to an observer standing on a plane at the level of the sea, since then its summit coincides with the horizon, and the whole arc falls below it. From the masts of ships we often observe rainbows forming a perfect circle. Such circular rainbows are also often observed in waterfalls and fountains.

Besides the rainbow already described, we also usually observe a second and larger one, concentric with the first, but having the order of the colours reversed, in the exterior rainbow the red being the inner, and the violet the exterior colour. The external rainbow is much the paler of the two, and has the colours much less strongly developed. Formerly it was erroneously believed that the second rainbow was a mere image of the first. The formation of the outer bow depends on exactly the some principles as that of the inner bow, and is

produced by the sun's rays, which have undergone a second refraction and a *second internal reflection* in the rain-drops.

In Fig. 523 is represented the course which a ray of light pursues in the rain-drop in order to be a second time reflected. *S A* is the incident ray, which is refracted in the direction *A B*, then reflected at *B* and *C*, and finally refracted at *D* in the direction *D O*. In this case the incident and the emergent rays intersect, forming with one another an angle *d*, whose magnitude varies according as the incident ray impinges on the drop at another place, therefore under another angle of incidence.

FIG. 523.



In this case the effective emergent red rays form an angle of 50°, and the effective emergent violet rays an angle of 53½° with the incident rays; the eye, therefore, perceives a series of concentric coloured rings, the innermost of which is red, and has a radius of 50°, whilst the outermost one, the violet, has a radius of 53½°.

The outer rainbow is the paler because it is formed by rays which have undergone a second internal reflection, and (as is well known) after every reflection light becomes weaker. We should be able to see a third, and even a fourth rainbow, formed by rays which had undergone three or four internal reflections, if the light of these rays were not too faint.

Halos and Parhelia.—When the sky is invested with light clouds, we often observe coloured rings close round the sun and moon. These rings are frequently imperfect, and mere portions. The fact that lunar halos are more frequently observed than solar halos, is dependent on the circumstance that the sun's light is too dazzling; the latter are, however, seen on observing the sun's image in still water, or in a mirror blackened at the back.

These halos present the greatest similarity to the glory observable round the flame of a taper on looking at it through a glass plate on which lycopodium seed has been strewed; in fact, both these phenomena depend on the phenomena of interference; the vesicles of vapour may replace the minute particles of seed in the latter case.

Sometimes we also notice two larger coloured circles around the sun and moon; these must not be mistaken for halos. The

radius of the smaller of these luminous rings appears under an angle of 22 or 23°, whilst that of the greater under an angle of 46° or 47°. The red in them is inverted inward; the inner edge is the sharper, the outer is more undefined and less decidedly coloured. The two circles rarely appear simultaneously. Fig. 524 exhibits

FIG. 524.

the phenomenon as we have most commonly the opportunity of observing it; the smaller ring has a radius of 22° or 23°; it is intersected by a horizontal streak of light, which often extends to the sun itself. The streak is brightest at the points where it intersects the ring of light; these bright spots, which we observe on both sides of the sun on the outer circumference of the ring, are the parhelia; sometimes one such parhelion appears vertically above the sun at the summit of the ring; but at this point also, there is often seen an arc of contact, as shown in Fig. 524. Moreover, we often observe parhelia without rings, or rings without parhelia. These rings and parhelia never appear in a perfectly unclouded sky, but only when it is overcast.

The appearance of these rings has been explained by assuming that light is refracted by the crystals of ice suspended in the atmosphere. If the icicles are six-sided prisms, the two non-parallel and non-joining sides always form with one another an angle of 60°; the icicles form, therefore, regular, equilateral,

triangular prisms, in which the minimum of deviation is about 23°. Rays, which have undergone in the icicles the minimum of deviation, are analogous to the active rays in the rainbow, since many rays emerge very nearly in the same direction. This hypothesis, therefore, explains at the same time the formation of the ring, its size, and the order in which the colours take place.

The ring of 46° is explained by the assumption that the axis of the prisms stands obliquely, in such a manner that the right angle which the lateral surfaces of the prism make with the base is the refracting angle of the prism. For a prism of ice, whose refracting angle is 90°, the minimum of deviation is, in point of fact, 46°.

The light streaks accompanying the parhelia are explained by the reflection of the sun's rays from the vertical surfaces of the crystals of ice. The streak is brightest where it cuts the ring of 23°, since here two causes co-operate to affect the stronger illumination.

Ignis Fatuus, or the *Will-o'-the-Wisp,* is the name usually given to certain flames seen in marshy lands, moors, churchyards, &c., in fact, wherever putrefaction and decomposition are going on; they usually appear a little above the ground, exhibit a flickering and unsteady motion, and soon again vanish. Although we are usually in the habit of treating these lights as thoroughly understood phenomena, there is yet great uncertainty regarding them, since they have not been sufficiently explained, and what is considered as matter of fact not at all times to be received, owing to the circumstance that most persons who have seen them were not in a state to make accurate observations, and to explain in an unprejudiced manner what they saw.

Volta held the opinion that these lights were caused by marsh gas (light carburetted hydrogen) inflamed by an electric spark. But from whence could the spark arise? Others are of opinion that they are caused by phosphuretted hydrogen, which inflames as soon as it comes into contact with atmospheric air; but then there would be a momentary flash accompanied by a puff of smoke, and not a prolonged feeble light, such as is observed. The most probable view is that they are caused by hydrogen gas containing phosphorus, which does not, properly speaking, burn as a flame, but is only faintly phosphorescent.

Falling stars, fire-balls, and meteoric stones.—The appearance presented by falling stars is so generally known as to require no detailed description. It has been ascertained by corresponding

observations that the height of falling stars averages 34 or 35 (German) miles, and that they move with a velocity varying from 4 to 8 (German) miles in a second.

A very remarkable phenomenon connected with falling stars, is the periodically recurring showers which have been observed from the 12th to the 14th of November, and on the 10th of August (the Feast of St. Lawrence); these periodic showers of stars of the latter date are noticed in an ancient English church calendar, and are termed the fiery tears of the Saint. One of the most considerable of these showers of stars was observed in North America on the 12th and 13th of November, 1833; they appeared to fall almost in contact, like flakes of snow in a snow-storm, and it was calculated, that in the course of nine hours no less than 240,000 fell.

Fire-balls appear to have the same origin and to be of the same nature as the falling stars just described, and to differ from them merely in size. Fire-balls have been seen amongst the great falling stars.

Fire-balls explode with a great noise, and stony masses then fall from them, known as *meteoric stones*, or *aërolites*. Even during the day-time such meteoric stones have been seen to fall, with a loud report, from small gray clouds.

Meteoric stones, just fallen, are still hot, and in consequence of the velocity of their fall, penetrate the earth to a greater or less degree.

About the era of the last century, there was a strong tendency to regard the falling of stony masses from the atmosphere as fabulous; but since that period various cases have occurred which have been observed by several persons, and have been attested to by men in whom confidence must be placed. We may especially mention the meteoric stone that fell at Aigle, in the department of Orne, on the 26th of April, 1803, examined by *Biot*, and that on the 22nd of May, 1808, and that at Stauners, in Moravia. On the 13th of November, 1835, (at the period, therefore, of the falling stars), a house in the department of Ain, was set on fire by an aërolite.

Meteoric stones have a peculiar physiognomy, by which they may be distinguished from all terrestrial fossils; but notwithstanding this, they differ so much individually, that *Chladni*, who devoted much attention to these subjects, regarded it as difficult to assign to them a general character. One of their

most marked characteristics is, however, their containing a certain amount of native iron, and a bituminous, glistening, sometimes raised external crust, which is scarcely ever absent. A further description would involve us too deeply in mineralogical details.

Stony masses have been found at various spots on the earth's surface, perfectly distinct in geological character from the mountain range in the vicinity, but presenting the greatest similarity to stones known to be of meteoric origin. Hence such masses are considered to be aërolites.

The mass of meteoric stones is often very great; they have been found weighing from a few pounds up to 400 cwt.

It can hardly be longer doubted that falling stars, fire-balls, and meteoric stones, are of cosmical origin, or that they are most probably masses which, like the planets, revolve round the sun, and, being drawn within the sphere of the earth's attraction, fall. The fire and light accompanying them, are most easily accounted for by the assumption that these minute spheres are surrounded with an atmosphere of inflammable gas, which inflames on entering into the oxygenized atmosphere of our earth. If we assume that, besides the innumerable individual masses of this kind revolving round the sun, whole swarms of them form a ring round that body, and further, that the plane of this ring cuts the earth's orbit at a definite point, we have an explanation of showers of the periodic falling stars.

CHAPTER V.

ON ATMOSPHERIC ELECTRICITY.

Original discovery of atmospheric electricity.—Otto von Guerike, the distinguished inventor of the air-pump, was the first who observed an electric appearance of light. About the same time, *Wall* noticed a vivid spark, and heard a strong rustling sound, on rubbing a large cylinder of resin, and it is a remarkable thing that the first sparks drawn by the human hand were compared to lightning. These sparks and these cracks seemed, says *Wall,* to a certain degree, to represent thunder and lightning. The analogy was surprising; in order, however, to test its truth,

and to detect, in so minute an appearance, the causes and laws of one of the grandest phenomena of nature, it was requisite that there should be a more direct proof. Whilst in Europe men occasionally asserted that lightning was actually an electric phenomenon, its experimental proof was established in America. *Franklin,* after making many electrical discoveries, especially on the Leyden jar, and on the influence of points, arrived at the happy idea of searching for electricity even in thunder clouds; he concluded that metallic points, placed on lofty buildings, would draw off the electricity from the clouds. He waited with impatience for the completion of a steeple then being constructed in Philadelphia; but, at length, weary of waiting, he had recourse to another plan, which gave him even more certain results. Since all that was requisite was to raise a body a sufficient height in the air, he conceived that a kite, a child's toy, would answer his purpose as well as the highest steeple. He availed himself of the first thunder-storm in order to try his experiment; accompanied by a single person, his own son, since he was afraid of ridicule if his attempt failed, he set off into the open country and began to fly his kite. A cloud of great promise passed over them without producing the least action. Another passed over, but he could draw no sparks, nor could he see any signs of electricity. At length the fibres of the string began to separate from one another, and he heard a rustling noise. Encouraged by these signs, *Franklin* applied his finger close to the end of the string, and then observed the emission of a spark, which was quickly followed by many others.

Franklin performed his experiment in June, 1752, it was universally repeated with the same results. *De Romas,* at Nerac, influenced by the first idea of Franklin, had likewise thought of making use of a kite instead of elevated points. Without having received any account of the results arrived at by *Franklin,* he obtained in June, 1753, very powerful evidences of electricity, owing to his ingenious contrivance of laying a fine metal wire the whole length of the string. In the year 1757, *De Romas* repeated his experiments, and obtained sparks of surprising size. "Let the reader only imagine," says he, "streaks of fire from 9 to 10 feet in length, and 1 inch in breadth, accompanied by a cracking, which was louder, or as loud, as a pistol shot. In less than an hour I obtained at least thirty such sparks, not to count the thousands which were 7 feet long, or less."

Notwithstanding the measures of precaution taken by this skilful experimentalizer, he was struck down by the violence of the charge.

These experiments prove most completely that lightning is only an electric spark.

Electricity during a thunder-storm.—On examining the electrical condition of the clouds which gradually pass over the kite, we perceive that they are sometimes charged with positive or negative electricity, and sometimes in a natural condition. Although we know nothing of the distribution of electricity in the clouds, the attraction and repulsion of the unequally, or equally electrified clouds, is doubtlessly the cause of the extraordinary motions observed in the heavens during a thunder-storm. During this general agitation of the atmosphere, we see lightning flash through the sky and hear the thunder roll. These phenomena we are now about to consider more attentively.

We often see lightning break from the clouds, and flash far across the sky. On observing this phenomenon below our feet, from high mountains, we are able to form a more correct idea of its extent, and all observers agree in stating that under similar circumstances they have observed flashes of lightning of at least a German mile in length; we also know that several flashes proceed from the same cloud; finally, it is known that lightning generally describes a zigzag line; this form is common to lightning, and to the electric spark.

The vesicles of vapour which form clouds, are not such perfect conductors as metals; and although we do not know the laws of equilibrium, and the distribution of electricity in imperfect conductors, it is still evident that they do not perfectly discharge themselves at once, and that they can be brought back to their natural condition by a few sparks; this explains the reason why the same cloud emits several flashes.

The length of the lightning appears also to be a consequence of the imperfect power of conduction in clouds, and the mobility of the particles of which they consist. We may obtain sparks of 1 metre in length, through dry air, from the conductor of the best kind of electrical machines; the sparks, however, are still longer when carried off over woollen or silk subtances that have been scattered over with dust; in the same manner we should also obtain longer sparks through a mist, if it did not too much diminish the tension of the electricity. In order to explain

the length of the lightning we must assume that, on the course which it takes, the particles of vapour are already electrified by induction, and that finally, when the lightning appears, the disturbed equilibrium is restored from one layer to another, and that to a certain extent, sparks only pass from one particle to another, while the electric fluid does not traverse the whole course intervening between the remotely separated clouds.

Thunder is not more difficult to explain than the noise of a small electrical spark, and arises from the vibrations of the powerfully agitated air. We see the light along the whole course of the lightning, and the report arises simultaneously upon the whole extent of the line; as, however, sound is more slowly propagated than light, traversing only 340 metres in one second, we see the lightning before we hear the thunder; an observer, standing near one end of the course of the lightning, will not at once hear the sound arising simultaneously at all points. If we assume that the lightning is 3400 metres distant, and the observer stands in the prolongation of its course, the sound will reach him from the most remote extremity of the lightning, only 10 seconds later than from the part lying nearest to him. As, consequently, sound reaches the ear of the observer only by degrees from different parts of the flash, he does not hear an instantaneous noise, but a more or less prolonged rolling of the thunder, increased in intensity by the echo of the clouds, and the duration of this sound depends upon the length of the lightning, and his position of the observer with regard to its course.

Not only during thunder-storms, but even during a clear state of the atmosphere, we may, by aid of a good electroscope, shew the existence of an electrical tension in the atmosphere.

With regard to the origin of atmospheric electricity, we actually know nothing, although a very great deal has been written on this subject. Some are of opinion that the electricity of thunder-clouds originates in a rapid condensation of the atmospheric aqueous vapour, and, therefore, that electricity is a consequence of the rapid formation of dense clouds.

Effects of lightning upon the earth.—If we suppose that a thunder-cloud hovers from 2 to 6 thousand metres above the sea, or over a large lake, and if we assume it to be charged with positive electricity, it will act inductively, the + electricity in the water will be repelled, and the — accumulated upon the surface of the water; this accumulation may be sufficiently great

to occasion a marked elevation of the water, being able to form a large wave, a water mountain, as it were, which will continue as long as the electrical condition lasts; this latter, however, may terminate in three different ways.

1. When the electricity of the cloud is gradually dissipated without any discharge taking place, the naturally electrical condition of the water will thus by degrees be restored. 2. When a flash passes between the thunder-clouds, or a flash takes place between the cloud and some remote places on the earth, consequently, when the cloud is suddenly discharged, the electricity accumulated on the surface of the mountain of water, quickly flows off, and is replaced by its opposite kind, and equilibrium is in this manner at once restored. 3. When the thunder-cloud is near enough, and sufficiently strongly charged with electricity, the lightning passes over. This direct stroke generally occasions a more considerable swelling up of the water than the back-stroke. Such a shock cannot take place without producing a mechanical action upon the ponderable elements.

We will now consider the actions of thunder-clouds upon land.

A gradual separation and reunion of the electricity produces no visible actions; it appears, however, that such disturbances of the electrical equilibrium may be felt by organic beings, and have been experienced by persons affected with nervous diseases.

The back-stroke is always less violent than the direct shock; and there is no evidence extant of its having occasioned ignition, although there is no lack of examples showing that men and animals have been struck dead by it; in these cases the bodies have no limbs broken, and present no trace of wounds or marks of burns.

The direct stroke produces the most fearful actions; on the lightning striking, it marks the spot where it struck the ground by one or more holes of various depths.

Everything that is raised above the surface is therefore peculiarly exposed to the stroke of the lightning; hence it happens that animals are struck down in the middle of a plain: other circumstances being the same, one is, however, safer upon a non-conducting than on a good conducting surface.

Trees are good conductors, owing to the sap circulating in them; when a thunder-cloud passes over, a strong accumulation of electricity takes place in the trees, and on this account we say

with justice that trees attract the lightning: we ought never, therefore, to seek protection during a thunder-storm under trees, especially under such as stand alone, or even under bushes standing exposed on a plain. Buildings are, generally speaking, constructed of metal, stone, and wood. The action of thunder-clouds on these substances varies with the difference of their nature. When the lightning strikes, it especially attacks the better conductors, whether they are free or surrounded by worse conductors; the distributing force of the atmospheric electricity acts as well upon the nail driven into the wall, as upon the weather-cock projecting in the air.

The mechanical actions of lightning are usually very violent. When lightning strikes a room, the furniture is thrown down and broken, and metallic substances are torn out and hurled far away. Trees are cleft and split asunder by lightning, we are usually able to trace a deep furrow, many centimetres in breadth, which runs from top to bottom, the peeled bark and the torn splinters may be found thrown far off, and we often observe at the bottom of the tree an aperture through which the electrical fluid passed into the ground.

The physical actions of lightning show a more or less considerable elevation of temperature. When lightning strikes a straw shed, dry wood, or green trees, a carbonization, or even ignition takes place; in trees there is seldom any trace of the former. Metals are strongly heated, melted, or volatilized by the lightning. Repeated strokes on high mountains produce evident traces of fusion.

Lightning-conductors consist of a pointed metallic rod, projecting into the air, and of a good conductor connecting the rod with the ground. The following conditions must be fulfilled where these instruments effect the purposes for which they are designed:

1. The rod must terminate in a very fine point.
2. The connection with the ground must be perfect.
3. No interruption must occur from the point to the lower part of the conducting rod.
4. All parts of the apparatus must have the same dimensions.

When a thunder cloud hovers over the lightning-conductor, the combined electricities of the rod and the conducting medium will be decomposed, the electricity will be repelled, which is the same as the one contained in the cloud, and diffuse itself freely in the earth, whilst the opposite electricity will be attracted

towards the point, whence it can flow freely into the air, and thus an accumulation of electricity in the lightning conductor will be rendered impossible. Whilst the conductor is thus in activity, and the opposite electricities pass through it in an opposite direction, we may without danger approach and even touch it, since no discharge is to be feared when there is no electrical tension.

If we assume that one of the three first named conditions is not fulfilled, that the point is blunt, the medium conducting into the ground imperfect or interrupted, it is evident that an accumulation of electricity in the lightning-conductor will not only be possible, but even unavoidable; it will then form a charged conductor, in which an immense mass of electricity will be accumulated, from whence we may draw stronger or weaker sparks.

If only the point be blunt, the lightning may strike, but it will follow the conducting medium without destroying the building.

If the conducting medium be interrupted, or the connection with the ground imperfect, the lightning may likewise strike, it will, however, distribute itself laterally to other conductors, and occasion the same disturbances that would occur if there were no lightning-conductor.

Yet more: a lightning-conductor having this deficiency is very dangerous even where the lightning does not strike; for when at any part of the conducting medium, the electricity is sufficiently accumulated, a spark may strike sideways, and crush or set fire to any objects. We may illustrate this by the following melancholy incident. *Richmann*, Professor of Physics at St. Petersburg, was suddenly struck dead by the emission of a spark which escaped from the lightning conductor attached to his house, the connecting medium of which he had interrupted in order to examine the electricity of the clouds. *Sokolow*, engraver to the Academy, saw the spark strike *Richmann* on the forehead.

After having stated what conditions must be fulfilled in order to make a lightning-conductor efficient, and what dangers may ensue from the neglect of these precautions, there still remains something to be said of the practical arrangement of this apparatus. *Gay-Lussac*, under the auspices of the Academy of Sciences, has, at the suggestion of the Minister of the Interior, drawn

FIG. 525.

FIG. 526.

FIG. 529.

up instructions relative to this subject, which leave nothing more to be desired, but from which we can only extract the most essential.

The rod of the lightning-conductor is about 9 metres in length; it is composed of three pieces, namely, an iron rod of 8,6 metres in length, a brass rod of 0,6 ditto, and a platinum needle of 0,05 long, taken together they form a cone sloping upward in a regular line. See Fig. 525.

The platinum needle is soldered to the brass rod with silver, and the place of junction surrounded by a covering of copper, as may be more clearly seen in Fig. 526.

The brass rod is screwed into the iron rod, and thence secured by means of transverse pins.

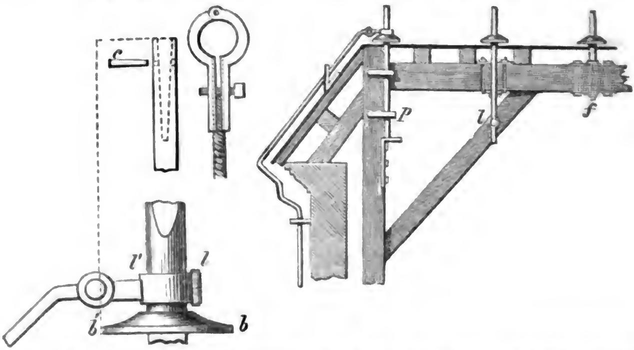
The iron rod is often composed of two pieces in order to facilitate its transport; one of these fastens into the other by means of a long conical projection, 2 decimetres in length, which is then secured by a transverse pin.

In Fig. 528 we see three different ways in which the rod may be fastened to buildings. Under the rod, about 8 centimetres from the roof a plate *b′ b′* (see Fig. 527) is screwed, in order to carry off the water 5 centimetres above this plate, the rod must be cylindrically and perfectly well turned, in order that a large screw *l l′*, Figs. 527 and 529 may be placed round it, in order to attach the conducting rod.

The conductor is a quadrangular iron rod, the side of which measures from 15 to 20 millimetres, and which is fastened to the ring *l l* by means of screws.

The conducting rod is carried over the roof and down the building into the ground. Everything depends upon bringing the conducting rod in as good a connection with the ground as possible. If there happen to be any well in the neighbourhood, which does not become dry, or if a hole can be bored to the

FIG. 527. FIG. 530. FIG. 528.



depth at which water is constantly to be found, it is sufficient as a means of conducting the rod, if we divide it into several arms. In order to increase the points of contact, the rod is conducted through windings to the well, or the bore-hole, which must then be filled with charcoal.

This affords the double advantage of protecting the iron the better from rust, and placing it in connection with so good a conductor as the charcoal. If there be no water in the neighbourhood, the rod must at least be connected with some damp spot by means of a long canal filled with charcoal. To effect a still greater degree of security we may branch the conducting rod off into several lateral canals.

A rope twisted round with copper wire, as seen in Fig. 530, is often used in the place of a conducting rod.

As we may easily see that the lightning cannot enter a conductor, constructed according to these principles, it will also as readily be understood that it cannot strike within some distance of the lightning-conductor. The electricity which pours copiously from the point, will be attracted by the thunder cloud, and when it has reached it, it neutralizes a part of the original electricity of this cloud.

If, therefore, a thunder cloud be near enough to the lightning-conductor to act inductively on it, its electrical force will also be weakened by the efflux of the opposite electricity from the point. The nearer the cloud approaches, the more strongly will its inductive force act, but the more also will it be neutralized by the efflux of the opposite electricity.

The efficiency of the lightning-conductor depends, however, likewise on other conditions. If other objects near it project beyond it, the electricity of the clouds may act more strongly upon them than upon it, and a discharge thus take place; the same is the case, when there are any considerable masses of metal, iron rods, or a metallic roofing in the vicinity of the lightning-conductor. In the latter case, we must bring the metallic masses into as good a connection with the lightning-conductor as is possible, in order that the attracted electricity may flow unhindered through the point. It is, consequently, dangerous to insulate metallic roofs from the conductors, as some practical philosophers have proposed doing. Fortunately, the means used to effect such an insulation are not sufficient for the purpose, and they have thus produced only useless results.

Experience shows us, that a lightning-conductor applied with all the necessary precaution, and of the dimensions indicated, is able to protect a circle having a radius of about 20 metres.

INDEX.

D.

E.

END.

LONDON:
Printed by Schulze and Co., 13, Poland Street.